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ELECTRICITY

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THE STUDENT'S TEXT-BOOK OF ELECTRICITY

BY

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'A MANUAL OF ELECTRICITY,' ETC. ETC.

A NEW EDITION, CAREFULLY REVISED

WITH AN INTRODUCTION AND ADDITIONAL CHAPTERS

BY

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PREFACE

TO

THE FIRST EDITION.

In the following pages it has been my endeavour to present a faithful reflex of the present state of Electrical Science. The work being specially intended for the use of students, much condensation was necessary in order to bring it within the limits of a moderate-sized volume. It will, nevertheless, I hope, be found to include the latest important discoveries, and the chief practical applications of the science. In carrying out the design of the book, I have availed myself freely both of the matter (in a condensed form) and of the illustrations of my 'Manual of Electricity;' but the present volume will be found to contain much additional and important information, which has become available since the publication of that work. In the composition of the chapters on Electric Telegraphy, I desire to acknowledge, with thanks, the assistance which I have received from the valuable 'Cantor Lectures,' delivered at the Society of Arts by that eminent electrical engineer Mr. Fleeming Jenkin, F.R.S. I am indebted to the same gentleman for the elaborate description of that beautiful electrical instrument invented by Professor William Thomson, F.R.S., viz. his

Portable Electrometer. The report of the joint committee 'On the Construction of Submarine Telegraph Cables' has supplied me with much information, that part detailing the investigations of Mr. Latimer Clark having been especially valuable. My thanks are also due to my friend Mr. Gassiot, F.R.S., who, with his well-known courtesy and kindness, has allowed me access to his Electrical Laboratory, and has given me an opportunity of witnessing there those marvellous phenomena connected with electrical discharge through different vacua, to the development of which he has devoted so many years of laborious research. It is almost needless to say that throughout the whole work Faraday's 'Experimental Researches' have been constantly consulted.

INTRODUCTION

TO

THE PRESENT EDITION.

THIS NEW EDITION of the 'Student's Text-book of Electricity' was projected by Dr. Noad shortly before his lamented death. It was taken in hand and partially edited before it fell to my lot to complete the work. Very little of the old matter has been excised, but much new matter has been introduced. The chief difficulty met with has been, not to know what to insert but what to exclude. The original plan has been carefully adhered to, so as to make it a reflex of the existing state of Electrical Science adapted for students.

Electricity and its applications have grown at such a pace that each particular branch demands almost a text-book of its own, and the ramifications of the science are so numerous that they embrace nearly every branch of physics in their sphere. Before the student can fairly claim to call himself an electrician he must be a fair *chemist* to comprehend the actions of the battery and the application of the current to electroplating; he must know much of *heat* to follow the laws of electricity; he must know something of *light* to understand its application to electric lighting; he must master the principles of *acoustics* to learn its latest development in telephony; he must be a *mathematician* to follow its quantitative applications; and he must be a bit of a *mechanic* to undertake its practical developments, especially

in telegraphy. This book has, however, been written under the idea that the student possesses none of these qualifications; and, therefore, that he approaches the subject from the datum line of ignorance.

Theory has been as much as possible excluded; first, because there really exists no theory of electricity properly so called; and secondly, because what theory there is, is used more for illustration than for explanation. Whether electricity is a form of matter or a form of energy is still undetermined, though most thoughtful electricians regard it simply as a form of energy. The Newton or Young of electricity has not yet arisen; and it remains for some master mind to gather together the threads and lace them into a connected form, so as to show that electricity is only another mode of motion like heat and light.

The grand theory of the conservation of energy is only now in its youth, and the principle of the atomic structure of matter is scarcely out of its cradle. The idea of a universe composed of atoms, linked together by some medium and in ceaseless motion, and that on the character of this motion depend heat, light, electricity, magnetism, chemism, sound, &c., is only now shaping itself into form in the mind of the philosopher.

In this conception of a universe we have only to regard matter and force. Matter is that which is perceptible by the senses; force is that which produces or tends to produce motion. Motion involves energy, and energy is the capacity for doing work. The application of force resulting in motion, therefore, implies energy exerted and work done. Time, space, matter, force, position, and motion are elementary ideas, upon which all our knowledge of physics is based. Motion is simply change of position. Force is the prime cause of every change of position. Force is the agent which renders matter perceptible. The two are inseparable and indestructible. We do not find matter nor can we produce force in their primitive states. The first is reduced to the elements; the second appears as modes of motion or forms of

energy. Energy is in reality the power of doing work—the power of moving matter against the action of some constraining cause, of motion against resistance. All the phenomena by which electricity is known to us are of a mechanical kind, and, therefore, are evidences of energy exerted. Hence the gradually increasing belief in the molecular theory of electricity, as opposed to the old and exploded notion that it is a highly elastic fluid.

Electricity is passing through precisely the same stages as its sisters Heat and Light have done. Early philosophers conceived each to be forms of matter, but they have been proved to be forms of energy. The processes by which this has been brought about have been slow and sure. Science is ever progressive. It very rarely retires from a position once assailed and captured. All the recent advances of electricity narrated in this book show an ever onward march towards the goal indicated above.

The applications of electricity have a decidedly civilising influence, and the tendency of all progress is to subdue this subtle agency more and more to be the helpmate of man. It has been utilised for domestic and commercial purposes. It has brought the whole world into one fold. It has annihilated space. It has turned night into day. It has rendered time uniform and exact, and it has enabled our geographers and astronomers to perfect the measurements of the dimensions of the earth. Thus it has become a great economiser of time, and a great regulator of the disposition of our movements, and, therefore, of our lives.

All sciences appear in their earlier stages to excite the imaginary powers of the mind, but in their later stages the calculating powers. The study of electricity has been a fine sphere for hypothesis, but it has now become a cultivated field for the exercise of the quantitative tendency of the mind. The development of its mathematical laws by Ohm, Weber, Gauss, Thomson, Kirchhoff; the discoveries of Galvani, Volta, Faraday, Ampère; the ingenious devices of Coulomb, Œrsted, Wheatstone, Daniell, Siemens—have made it an exact science.

It is now possible to calculate to within a few yards the distance of a rupture of a submarine cable at the bottom of the deep Atlantic, to prophesy the exact number of words which cables thousands of miles long would transmit, to calculate the steam power necessary to produce a given light in a given spot, and to measure approximately the dimensions of an atom.

Though thunder roared and lightning flashed from the creation of the world, and the ancients were well acquainted with the peculiarities of the friction of certain bodies, it was not until the seventeenth century that an electric machine was produced. The first half of the eighteenth century was marked by the introduction of the Leyden jar, and the second half by the discovery of the lightning rod. The nineteenth century commenced with the discovery of the galvanic battery and of the electric arc, and the different epochs of this prolific century may be marked by the discoveries of electro-magnetism, induction, and magneto-electricity. Hence discovery seems to have progressed with marvellous strides; nevertheless, discovery has now apparently ceased, and practical applications have commenced their career; and it is to give a faithful account of these that this fresh edition of Dr. Noad's valuable text-book is launched forth.

There is no royal road to a knowledge of the science of electricity. The student must advance by steady, persistent toil. All our knowledge of the facts of the science have been acquired by observation and experiment, and it is by these two assistants that the student must proceed. This book can only help him over difficulties which active observation will bring to his notice. The facts that are therein narrated should be verified by experiment. The student should as much as possible rely upon apparatus made with his own hands; but, when he has neither the power nor the means to construct them, he should avail himself of those opportunities which the numerous institutions in this country place at his command in the way of lectures and demonstrations.

There is a certain fascination in experiment which carries one through the elements of a science with ardour and pleasure; but the student who is facile in observing is much tempted to soar beyond the verification of recorded facts, and to conceive that he is discovering. Now, the recorded facts of electric science are but a small fraction of those unrecorded. In any course of research the negative results far outnumber the positive. Hasty generalisation and false reasoning on imperfect experiments are the greatest drawbacks to progress. The student must carefully guard himself against drifting upon these shoals, and must leave discovery until he has passed through the stage of studentship and reached that of mastership. Moreover, he should treat with great diffidence any result that may savour to him of a new fact. Nevertheless, research in a new field is a very healthy exercise to the mind and discipline to the reasoning powers when experiment is seconded by logic, but it should not be attempted until the days of studentship are over.

I have been materially aided in my task by my assistants Mr. H. R. Kempe and Mr. J. P. Edwards, and my thanks are herewith gratefully tendered to them for their help.

W. H. PREECE.

January 31, 1879.

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THE STUDENT'S
TEXT-BOOK OF ELECTRICITY.

CHAPTER I.

FRICTIONAL ELECTRICITY.

Fundamental Phenomena—Conductors and Insulators—Opposite Electricities—Electroscopic Apparatus—Law of Electrical Attraction and Repulsion.

(1) **Fundamental Phenomena.**—*Vitreous* substances, such as glass, become electrical by being rubbed with certain other substances; in this state they attract light bodies. *Resinous* substances, such as sealing wax and gutta-percha, become also electrical when rubbed with certain other substances; in this state *they* also attract light substances.

Bodies which have been once attracted, either by excited glass or excited resin, will not be attracted by the same substances again, until they have touched some body in conducting communication with the earth, but will be repelled.

A body which, having been attracted by an excited *vitreous* substance, is then repelled by it, is attracted by an excited *resinous* substance; so also a body which is repelled by an excited *resinous* substance is attracted by an excited *vitreous* substance.

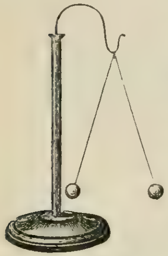
Bodies charged with the same kind of electricity repel each other, and bodies charged with opposite kinds of electricity attract each other.

Some substances (ebonite, silk, gutta-percha, glass) possess within certain limits the power of *insulation*; that is, they prevent the escape of electricity through them to the earth.

Other substances (metals especially) have no such power. But no substance is an absolute insulator or non-conductor; neither is there any substance which can be called a perfect conductor of electricity.

For illustrating the primary phenomena of electricity the only materials required are a tube of stout glass 18 or 20 inches long, and about an inch in diameter; a stick of common sealing wax; or, still better, an *ebonite* paper-knife and a pair of pith-balls suspended from a convenient support by silk threads. The glass tube, dry and warm, should be rubbed briskly for a few seconds with a dry warm silk handkerchief; it will then be found to have acquired the properties of attracting, and then repelling the pith-balls. The wax may be excited by rubbing it with a piece of dry warm flannel.

Fig. 1.



For exhibiting the phenomena of attraction and repulsion at a considerable distance, a long stick balanced on a small globe of glass, placed on a convenient support, will be found very useful. A pair of pith-balls suspended by thin metallic wires or black cotton threads should also be provided, to show the impossibility of giving a permanent electrical charge to the pith-balls when *uninsulated.*

The mutual attraction of oppositely electrified bodies, and the mutual repulsion of bodies similarly electrified, are well illustrated by suspending from silk threads two excited sticks of wax and two excited tubes of glass. On bringing them near each other, the wax will repel the wax and the glass will repel the glass, but a glass rod and a wax rod will manifest a strong mutual attraction.

(2) **Conductors and Insulators.**—In the following list the bodies are arranged in their order of conducting power, according to the present state of knowledge on the subject; and though probably not absolutely correct, it will serve to show how insensibly conductors and non-conductors merge into each other. Faraday thinks that conduction and insulation are only extreme degrees of one common condition; that they are the same in principle and in action, except that in conduction an effect common to both is raised to the highest degree, whereas in insulation it occurs in the best cases only in an almost insensible quantity:—

All the metals	Lime
Well-burnt charcoal	Dry chalk
Plumbago	Native carbonate of baryta
Concentrated acids	Lycopodium
Powdered charcoal	Caoutchouc
Dilute acids	Camphor
Saline solutions	Siliceous and argillaceous stones
Metallic ores	Dry marble
Animal fluids	Porcelain

Sea water	Dry vegetables
Spring water	Baked wood
Rain water	Leather
Ice above 13° F.	Parchment
Snow	Dry paper
Living vegetables	Hair
Living animals	Wool
Flame smoke	Dried silk
Steam	Bleached silk
Salts soluble in water	Raw silk
Rarefied air	Transparent gems
Vapour of alcohol	Diamond
Vapour of ether	Mica
Moist earth and stones	All vitrifications
Powdered glass	Glass
Flowers of sulphur	Jet
Dry metallic oxides	Wax
Oils, the heaviest the best	Sulphur
Ashes of vegetables	Resins
Ashes of animal substance	Amber
Many transparent crystals	Gutta-percha
Dry ice below 13° F.	Shell lac
Phosphorus	Ebonite

(3) **Opposite Electricities.**—We have seen that excited resin and excited glass, though they both attract light substances, exhibit each *a different kind of force*. Hence the term *resinous* electricity as applied to the former, and *vitreous* electricity as applied to the latter. These terms are, however, objectionable, implying, as they do, that when *vitreous* bodies are excited they are always electrified with one species of electricity, and that when *resinous* bodies are excited they are always electrified with the other. But this is by no means the case; for example—

1. When a glass rod is rubbed with a woollen cloth, it repels a pith-ball which it had once attracted; but if the cloth be presented, it will be found to attract the excited ball. We hence conclude that as the gas was *vitreously* electrified the woollen cloth must be *resinously* electrified.

2. When a stick of sealing wax is rubbed with a woollen cloth, it repels a pith-ball which it had once attracted; but if the cloth be presented, it will be found to attract the excited ball. Hence, by a similar reasoning, we are led to the inference that the cloth is *vitreously* electrified.

3. When a piece of polished glass is rubbed first with a woollen cloth, and then with the fur of a cat, and examined after each excitation by a pith-ball, it is found in the first case *vitreous* and in the second *resinous*. A woollen cloth and a piece of glass may thus be made to exhibit both kinds of electricity.

The terms *vitreous* and *resinous* do not, therefore, convey to the mind a proper impression of the nature of the two forces. The

terms *positive* and *negative* are less open to objection, although they take their origin in a theory of electricity which is not now recognised as compatible with observed phenomena. *Positive* electricity, then, is that which is produced upon polished glass when rubbed with a woollen or silk cloth; and *negative* electricity is that which is produced upon a stick of sealing wax when rubbed.

The signs + and − are generally used to denote positive and negative electricity.

(4) **One kind of Electricity cannot be produced without the other**—

1. If two persons stand on two stools with glass legs, and one strike the other two or three times with a well-dried cat's fur, he that strikes will have his body charged *positively*, and he that is struck will be electrified *negatively*.

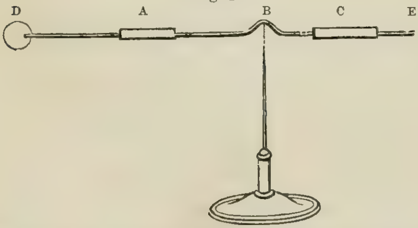
2. If on a dry day a person stand on a stool with dry glass legs and connect himself electrically with a gold-leaf electroscope (Fig. 4), and if then one standing on the floor draw a comb rapidly through the hair of the other, the gold leaves will diverge with *positive* electricity. If the person using the comb stand on the insulating stool, the leaves of the electroscope will as he combs diverge with *negative* electricity.

(5) **Electroscopic Apparatus.**—Instruments for indicating the presence and kind of electricity are called *electroscopes*; those by which the electricity is under various conditions measured are called *electrometers*.

The electroscope of Gilbert and Haüy consisted of a light metallic needle, terminated at each end by a light pith-ball covered with gold leaf, and supported horizontally by a cap at its centre on a fine point; the attractive or repulsive action of any electrified body presented to one of the balls being indicated by the movements of the needle.

A useful modification of this electroscope is shown in Fig. 2. It consists of a short bent brass wire A B C, to either end of which is fixed a reed, so as to form arms of unequal length. The longer arm carries at its extremity a disc of gilt paper D, about half an inch in diameter, and the shorter arm a small metallic ball, E. The whole is balanced on a finely pointed wire, supported on a rod of varnished glass The arms are elongated or contracted, and the balance thus adjusted, by sliding the reeds upon the wire. The disc D is electrified either positively or negatively, and the body the nature of the electricity of which is to be examined is presented to it. If we desire merely to detect the presence of

Fig. 2.



electricity by its attractive force, we uninsulate the needle by hanging a metallic wire from the pointed rod of support, and then present the excited substance to the disc.

Another useful form of electroscope is shown in Fig. 3. The gilt disc is attached to a slender stick of shell lac, which is suspended from a wooden frame by a fine silk. A charge of electricity communicated to the disc will be retained for a long time even under unfavourable circumstances; this simple instrument is well adapted, therefore, to the lecture-room.

Fig. 3.

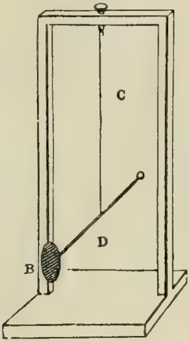
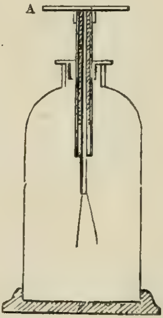


Fig. 4.



Singer's modification of Bennett's gold-leaf electroscope is shown in Fig. 4. Two slips of gold leaf are attached to a brass wire firmly secured in the centre of a varnished glass tube by a band of gutta-percha. The glass tube is fixed in the cap of a glass jar, and to the upper end of the wire a brass cap A is screwed. The mode of manipulation with this instrument will be described in the next chapter.

Fig. 5 represents Sir William Snow Harris's electroscope. A small elliptical ring of metal, *a*, is attached obliquely to a small brass rod by means of a short tube of brass; the rod terminates in a brass ball *b*, and is insulated through the substance of the wood ball, *n*. Two arms of brass *r r* are fixed vertically in opposite directions on the extremities of the long diameter of the ring, and terminate in small balls; and in the direction of the shorter diameter within the ring there is a delicate axis set on extremely fine points: this axis carries by means of short vertical pins two light reeds of straw *s s*, terminating in balls of pith, and constituting a long index corresponding in length to the fixed balls above mentioned. The index thus circumstanced is susceptible of an extremely minute force; its tendency to a vertical position is regulated by small sliders of straw, movable with sufficient friction on either side of the axis.

To mark the angular position of the index in any given case, there is a narrow graduated ring of card-board or ivory placed behind it. The graduated circle is supported on a transverse rod of glass by the intervention of wooden caps, and is sustained by means of the brass tube *d*, in which the glass rod is fixed. The whole is insulated on a long rod of varnished glass

A, by means of wood caps terminating in spherical ends. In this arrangement, as is evident, the index diverges from the fixed arms whenever an electrical charge is communicated to the ball *b*, as shown in the lower figure.

The instrument is occasionally placed out of the vertical position at any required angle by means of a joint at *m*, and all the insulating portions are carefully varnished with a solution of shell lac in alcohol.

This instrument is, to a certain extent, an *electrometer*, as well as an electroscope; but its applications as a measurer of electricity are, as Harris observes, very limited; for although the amount of divergence does increase with the quantity of electricity in operation, we are not able to ascertain the ratio of increase because of the diminishing force of repulsion as the divergence increases.

Fig. 5.

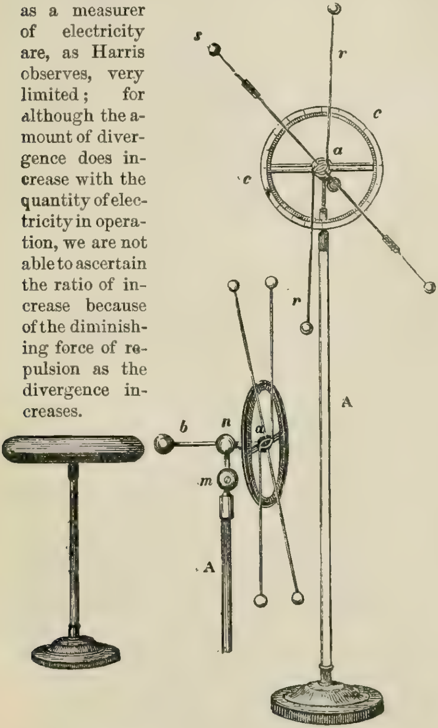
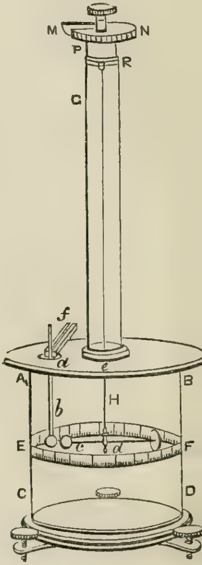


Fig. 6.



The torsion balance electrometer of Coulomb is shown in Fig. 6. A B C D is a glass cylinder, which is covered with a plate of glass, A B. This plate is perforated with the two holes *e* and *a*, the former being intended to receive a tube of glass *e* G, two feet high, carrying on its upper end a torsion micrometer, consisting of a graduated circle M N, an index M, and a pair of pincers opened and shut by a ring, for holding a slender silver or glass wire G H, whose lower end H is also grasped by a similar pair of pincers made of

copper, and about a line in diameter. Through a hole in these copper pincers there passes a horizontal needle *c d*. This needle consists of a silk thread or a straw covered with sealing wax; at the end of it, at *d*, about eighteen lines long, is a cylinder of gum lac. It is terminated at *c* by a ball of pith of elder, about two or three lines in diameter, and at *d* by a vertical vane of paper covered with turpentine. A circular band of paper, E F, divided into 360°, is pasted round the cylinder, on a level with the needle, and at the hole *a* there is introduced a small cylinder *a*, *b*, the lower end of which, made of gum lac, carries another ball *b* of elder pith. The instrument is adjusted, when a line passing through the course of the silver wire G H at P, passes also through the curves of the balls *b* and *c*, and points to the curves of the graduated circle E F.

In this instrument the force of electrical repulsion is balanced against the reactive force of the glass or silver thread, which is twisted more or less from its quiescent position. In using it a charge is communicated to the ball *b*, which is then brought into contact with the ball *c*; mutual repulsion takes place (Fig. 1), and the needle *c d* is turned through a certain arc. By turning, however, the micrometer button in the direction N P, the wire G H is twisted and caused to return to its first position, and point to the zero of the scale; this being done, it is evident that the force of torsion has been made to balance the repulsive force of the two balls *e*, *c*, and that by comparing the force of torsion which balances the repulsive force at different distances of the balls, measures of the repulsive forces at these distances may be obtained.

In applying this instrument to the determination of the law of attractive force between two oppositely electrified bodies, a slight modification is requisite in order to prevent the balls from rushing into contact, in consequence of the attractive force increasing in a greater ratio than the force of torsion. This difficulty is provided against by extending a thread of fine silk vertically between the top and bottom of the case, having its ends attached to them by wax, and allowing the fixed ball to remain in contact with it at the commencement of the experiment. When the two discs are oppositely electrified, the movable disc is forced from the fixed disc by turning the micrometer in a direction contrary to that in which it was moved in the former experiments.

Faraday employed Coulomb's balance electrometer in his researches on induction; he thinks that, though it requires experience to be understood, it is a very valuable instrument in the hands of those who will take pains by practice and attention to learn the precautions needful in its use.

(6) **Law of Electrical Attraction and Repulsion.**—Two spheres charged with similar electricities repel each other with a force inversely proportional to the *squares of the distances* between their centres.

This law was established by Coulomb with his torsion electrometer. The following was one of his experiments:—An electrical charge was communicated to *b*, which was then brought into contact with *c*; the latter was repelled, and finally took up a position at an angle of 36° from *b*. The wire G H had therefore become twisted through an angle of 36°. The micrometer button was now turned, till the distance between the balls was

diminished to 18°; but to do this, the index M required to be moved over 126° of the graduated circle M N. Now 126° added to 18° (the former torsion) = 144°. The reactive force of torsion at 36° and 18° is, therefore, 36 and 144, or, in other words, when the distance is diminished *one-half* the force has increased *four times.*

The law for attraction is the same, the energy of the attractive force being diminished in the same proportion as the *square of the distance* between the electrified bodies is increased.

The truth of Coulomb's law has been confirmed by Sir William Snow Harris, to whom electrical science is indebted for many beautiful discoveries and important practical applications. Sir William's experiments on electrical attraction led him to the following results:—

1. That the forces between two spheres will be inversely as the distances between their nearest points multiplied into the distance between their centres.

2. That two spheres at the distances 2·2, 2·5, 2·8, and 3·0 inches exert the same force as two circular plates at the distances of 0·664, 1·117, 1·496, and 1·732 inches respectively.

3. That the attractive force of two opposed conductors is not influenced by the form or disposition of the unopposed portions. The attractive force, for example, is the same, whether the opposed bodies are mere circular planes or planes backed by hemispheres or cones. Two hemispheres also attract each other with the same force as the spheres of which they are hemispheres.

4. The force between two opposed bodies is directly as the number of attracting points, the distance being the same. Thus two circular planes of unequal diameter do not attract each other with a greater force than that of two similar areas each equal to the lesser. In like manner, the attractive force between a ring and a circular area of the same diameter is equal to that exerted between two similar rings, each equal to the former.

5. The attractive force between a spherical segment and an opposed plane of the same curvature is equal to that of two similar segments on each other.

For the measurement of small forces of repulsion, Harris employed a new arrangement of the balance of torsion, which, from the peculiar mechanical principle on which it depends, he calls the 'Bifiliar Balance.' (*Phil. Trans.* 1836.)

The reactive force in this instrument is not derived from any principle of elasticity, as in Coulomb's, but is altogether dependent on gravity. It is obtained by means of a lever at the extremity of two parallel and vertical threads of unspun silk, suspended within a quarter of an inch of each other from a fixed point. The threads are stretched more or less by a small weight, and the repulsive force is caused to operate much in the same way as in Coulomb's balance of torsion. As the threads tend to turn, as it were, upon each other, the stretching weight becomes raised by a

small quantity, and thus gravity is brought to react against the repulsive force in operation. The delicacy of this balance is extremely great, and is said to render sensible a force of $\frac{1}{50000}$th part of a grain.

Sir William's experiments on the relation of the repulsive force to the quantity of electricity led to the following result:—

1. The discs being charged *equally*, and to a given intensity, the forces vary *in an inverse ratio to the squares of the respective distances*; when, however, the quantity on one of the discs is diminished, that is, when they are charged unequally, this law is only apparent up to a certain limit: sometimes at certain distances the law is in *an inverse ratio of the simple distance*, or nearly approaching it; and at other distances the law of the force becomes irregular, until at last the repulsion vanishes altogether, and is superseded by attraction, being apparently disturbed by some foreign influence.

2. The quantities of electricity contained in either of the repelling bodies are not always proportional to the repulsive forces—a result which, although anomalous and unsatisfactory, Harris believes to be in accordance with the general laws of electrical action: the force of *induction*, for example, not being confined to a charged and neutral body, but operating more or less freely between bodies similarly charged, it is evident that the inductive process between bodies similarly charged may become indefinitely modified by the various circumstances of quantity, intensity, distance, &c., giving rise to apparently complicated phenomena.

According to Coulomb, the relative electrical capacities of a solid or hollow sphere and a circular plate of equal area are as two to one; and in expanding a globe into a plane circular area of the same superficial extent each side to each side we double its capacity by giving it another exterior surface. Twice the quantity of electricity may therefore now be placed on it under the same intensity. If this view be correct, by substituting for the circular plate a second sphere, whose exterior surface is equal to the *two surfaces* of the plate, the result would be the same as before; but Harris found

That the electrical reactions after the respective contacts with the plate and sphere, the areas of which are equal, instead of being as two to one, as they should have been according to Coulomb's theory, were nearly the same; and hence he concludes that the result arrived at by Coulomb's method of experiment may be classed with those cases in which the repulsive force exercised by the balance is not proportionate to the quantity of electricity.

His experiments further show—

1. That the capacity of a sphere is the same as that of a circular plane of equal area into which it may be supposed to be expanded.

2. That a spherical conductor either hollow or solid, and a plate of equal area, have the same electrical capacity.

3. That the quantity of electricity taken from the surface of a charged

body by a small insulated disc of considerable thickness may be greatly influenced by the position of the point of application, *independently* of the quantity of electricity; so that the same quantity may possibly exist in two different points, and yet the proof plane become charged in a different ratio, the inductive power of the plate being different in these points.

CHAPTER II.

FRICTIONAL ELECTRICITY (*continued*).

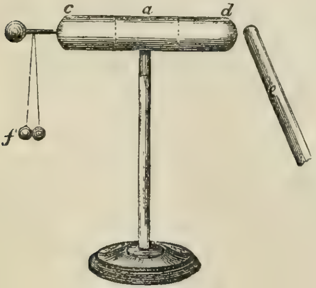
Induction—The Electrophorus—Specific Inductive Capacity—Distribution—The Condenser.

(7) **Influence of Excited Bodies upon Neutral Conducting Bodies at a Distance.**—We have seen that absolute contact between two bodies is not necessary for the development of electrical phenomena. An excited rod of glass, or of sealing wax, causes a suspended pith-ball to move from its vertical position when presented to it, and while at some distance; so also feathers and other light substances leap towards an electrified body brought into their vicinity.

This influence of electrified bodies on bodies at a distance is called *electrical induction*, and the resulting effect *induced electricity*.

There is scarcely any electric phenomenon in which inductive action does not come into play. 'All charge,' says Faraday (*Ex. Research.* series xi. p. 1178), 'is sustained by it. All phenomena of intensity include it. All excitation is dependent on it. It appears to be the essential function both in the first development and the consequent phenomena of electricity.'

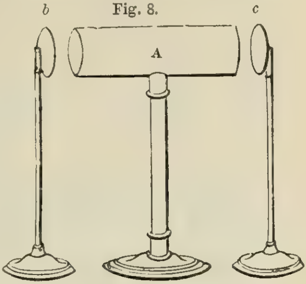
Fig. 7.



1. Let *d a c* be a cylinder of brass supported on a glass stand, and furnished with a pith-ball electroscope *f*. Let an excited glass tube be held at a distance of about six inches from *d*; the pith-balls will be seen to diverge, indicating the presence of free electricity. Remove the glass rod, and the pith-balls will fall together, showing that they are no longer electrified. Again advance the glass tube, the balls will again diverge, and again collapse on withdrawing the tube, and so on.

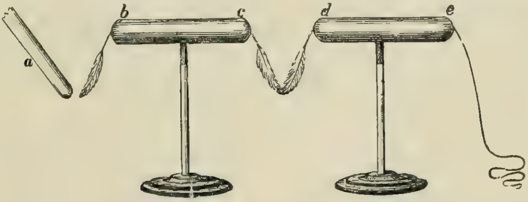
2. Let A be an insulated cylindrical conductor five or six inches long and about three inches in diameter, and let *b* and *c* be two thin metallic discs, and insulated on glass rods, and of such a size as to fit accurately the ends of the conductor, so that when in their places the whole system may represent one conducting surface. Now, having given a large metallic ball a charge of *positive* electricity, suspend it from a silk thread, about three inches from the disc *c* and in a right line with the cylinder A. Next remove the disc *c*, by its insulating stand, and examine its electrical conditions, it will be found to be *negative*; remove and examine *b*, it will be found to be *positive*.

Fig. 8.



3. Let two metallic cylinders *b c*, *d e*, supported upon rods of varnished glass, be placed within an inch or more of each other in a right line; the cylinder *b c*

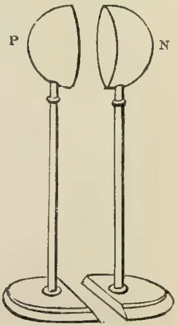
Fig. 9.



must be insulated, but the end *e* of the cylinder *d e* may be connected with the earth by a metallic wire; let feathers or light pith-balls be suspended by linen threads from *b*, *c*, and *d*; on bringing an excited rod of glass or wax *d* within three or four inches of *b c*, the feather or ball hanging from *b* will be attracted, and at the same time those suspended from *c* and *d* will rush together.

4. Let P and N be two hemispheres of wood, covered with tinfoil, mounted on rods of varnished glass, and standing on wooden feet, so that they may be placed in contact with each other. While thus in contact, let an excited rod of glass be brought near; then let it be removed, and let the condition of the hemispheres be examined; neither will be found to have received any electrical charge. Let the experiment be varied by separating the two hemispheres while under the influence of the excited electric; and on examining them it will be found that they have each acquired an electrical charge—one *positive*, and the other *negative*.

Fig. 10.

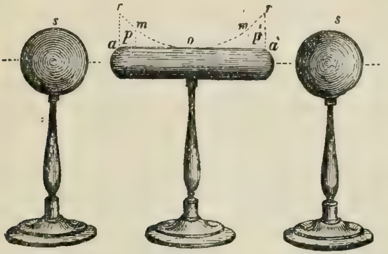


5. Arrange a long insulated cylindrical conductor, with one extremity,

about a quarter of an inch from a jet from which a gentle stream of gas is escaping; let a well-excited glass rod be suddenly brought near the other end, the gas will seldom fail to become inflamed. While the excited tube is still in the immediate vicinity of the conductor, let the flame be extinguished, then let the excited tube be suddenly withdrawn, and the gas will generally be reinflamed.

6. Let s s' be two insulated metallic spheres, and a $\grave{a}$ an insulated metallic conductor; suppose s to be strongly charged with *positive*, and s' with *negative*, electricity. If the electrical condition of a $\grave{a}$ be examined, it will be found that the only part which is free from electricity is the centre o, that half extending from o to a is electrified *negatively*, and that half extending from o to $\grave{a}$ *positively*. The intensities of the opposite electricities at the extremities will be found to be equal, and at any point equally distant from the centre, as p p', the depths of the electric fluid will be equal, and the electric state of each half may be correctly represented by the ordinates $p\,m$, $p'\,m'$ of two branches of a curve which are precisely similar and equal.

Fig. 11.



7. Whilst the conductor d a c (Fig. 7) is under the influence of the excited glass, and the pith-balls divergent, let it be touched with the finger; the pith-balls will instantly collapse. Let the finger be removed, and then let the glass tube be suddenly withdrawn, the pith-balls will again open, and *will remain divergent*. On examining the nature of the electricity with which they are charged, it will be found to be *negative*.

8. Hold an excited tube of glass at some distance above the cap of the gold-leaf electroscope (Fig. 4), the leaves will open, having received by induction a charge of *positive* electricity; remove the tube and the leaves will collapse. Again advance the excited glass, and, whilst the leaves of the electroscope are open, touch the cap of the instrument with the finger, and then quickly withdraw the glass tube; the gold leaves will now be found charged with *negative* electricity. Conversely, if an excited stick of wax be used instead of the tube of glass, and the same manipulations performed, the leaves will be found to be charged with *positive* electricity, which charge, if the instrument be dry and warm, may be maintained for several hours.

From these experiments we learn—

1. That the electrical disturbance of a neutral conductor by the proximity of an electrified body is of a temporary nature only, all signs of excitement disappearing immediately the electrified or *inducing* body is removed.

2. That this electrical disturbance consists in the temporary decomposition of the natural electricity of the conductor in such a manner that the electricity of the contrary name to that of the inducing body is drawn

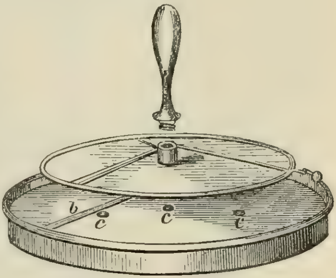
towards that end of the conductor nearest the inducing body; while the electricity of the same name is driven to the opposite end.

3. That by making the conductor of two or more parts each insulated and movable, the opposite electricities thus accumulated on the ends of the conductor may by management be retained after the removal of the inducing body.

(8) **The Electrophorus.**—This very useful instrument is founded on the principles of induction. It consists of three parts—1. A cake of resinous matter, composed of shell lac, Venice turpentine, and resin; 2. A conducting plate or *sole*, which is merely a metallic dish into which the melted resinous composition is poured; 3. A cover of metal, or of wood covered with tinfoil, provided with a varnished glass handle. Fig. 12 represents a modification of the instrument by Mr. Phillips, a strip of tinfoil, *b*, being pasted across the surface of the resinous plate and united at each end with the metallic sole; or preferably, brass wires, *c c c*, being inserted from the sole through the resin, the tops being level with the surface.

Let the surface of the resinous cake be well excited by holding it by its *sole* in a slanting direction, and striking it briskly several times with a piece of dry warm fur or flannel, or with a warm silk handkerchief; let it now be laid on the table and the cover placed upon it. If the latter be now removed by its handle, it may possibly be found to have acquired a feeble charge of *negative* electricity, but it will require a delicate electroscope to detect it. Let it be replaced on the resin, touched with the finger, and then raised; it will now be found to be strongly charged with *positive* electricity, and a spark will pass between it and a conductor brought sufficiently near.

Fig. 12.



The electrophorus which was invented by Volta is of great use to the electrician, as affording a ready supply of statical electricity. When once charged, the resinous cake retains its electricity for a long time, as it acts solely by its inductive influence on the natural electricity of the cover.

When the metallic plate is placed on the excited resin, its condition is that of a conductor under the influence of an electrified body, its lower surface becoming *positive* and its upper surface *negative* by induction. When it is removed from the resin the separated electricities re-unite; but when the plate is *uninsulated*

while in contact with the resin, the repelled negative electricity is neutralised by a corresponding quantity of positive electricity from the earth, and the cover becomes charged with positive electricity, which cannot be compensated with a corresponding quantity of negative electricity from the resin, because of the non-conducting power of the latter.

The negative electricity of the upper surface of the resin acts inductively on the natural electricity of the lower surface, attracting the positive and repelling the negative; the latter escapes or becomes neutralised through the medium of the conducting sole; the positive electricity cannot escape, being bound by the negative electricity of the upper surface. Thus it is that the charge on the resin is retained.

The electrophorus is only an exceedingly convenient source of electricity, but it serves admirably to illustrate the operation and principle of induction.

(9) **Faraday's Theory of Induction.**—It was by an apparatus constructed on the principles of the electrophorus that Faraday demonstrated the important electrical fact *that induction is essentially a physical action, occurring between contiguous particles.* He considers that the electric force originating or appearing at a certain place is propagated to, and sustained at a distance, through the intervention of the intervening particles of air, each of which becomes *polarised,* as in the case of insulated conducting masses.

Suppose P to be a positively charged body, and N P a previously neutral body at a distance, the action at P is transferred to N P through the medium of intervening molecules, each of which becomes *electro-polar,* or disposed in

Fig. 13.

an alternate series of positive and negatives poles, as indicated by the series of black and white hemispheres.

Again, let three insulated metallic spheres A, B, C, be placed in a line, but not in contact. Let A be electrified positively, and then C uninsulated. Under

Fig. 14.

these circumstances B will acquire the negative state at the surface towards A and the positive state at the surface farthest from it, and C will be charged negatively. The ball B will be in what is called a polarised condition: that is, the opposite parts will exhibit the opposite electrical states; A and C will

not be in this polarised state, for they will be, as it is said, charged the one positively and the other negatively.

This theory of induction does not, however, rely on the polarisation of *matter* in the ordinary acceptation of that term. It proposes rather to deal with the *powers* or *forces* which, in the generally received view of the atomic constitution of matter, are associated with the material atom, giving to it its characteristic effects and properties. Faraday adopts the theory of Boscovith, according to which atoms are mere centres of forces or powers, not particles of matter in which the powers themselves reside. In their quiescent state, these *centres of force* are not arranged in a polarised form, but they become so under the influence of contiguous and charged particles. When this forced or polar condition is readily assumed, it is readily destroyed, and *conduction* is the result. When the contiguous particles communicate their forces less readily, *insulation,* more or less perfect, is the consequence, and the action of a charged body on insulating matter is *induction.*

(10) **Relation of Induction to the matter through which it is exerted.**—All insulating bodies do not possess in the same degree the power of transmitting the electric influence. The relative facility with which they do so, as compared with a common standard, is termed by Faraday their *specific inductive capacity.*

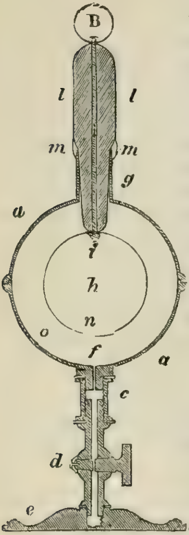
1. Let a small electrical charge be communicated to a metallic disc, and let it be suspended by a silk thread, an inch or so above the cap of the gold-leaf electroscope, the leaves of the instrument will immediately diverge to a certain extent by induction. Now, let a plate of shell lac about an inch in thickness, and mounted on an insulating handle, be inserted between the electrified disc and the cap of the electroscope, the divergence of the gold leaves will immediately increase, because induction takes place more freely through shell lac than through air.

2. Let three equal discs of brass be arranged parallel, and at equal distances from each other: the two exterior must be in communication with the ground; the third, which is between them, must be insulated. Let a single gold leaf be suspended exactly equidistant between the two brass balls, each of which communicates separately with one of the exterior discs. Let a small electrical charge be communicated to the middle disc, and then let the communication between the two exterior discs and that ground be cut off. Under these circumstances, the gold leaf will remain at rest, being equally attracted by each of the balls; and the insulating stratum separating the three discs is the same—viz. *air.* Now let a stratum of some other insulating substance, such as *lac*, *sulphur*, or *glass*, be interposed between two of the *discs*, the gold leaf will immediately diverge, showing that the inducing action of the electrified body upon the disc, from which it is separated by the new insulating body, has become greater than before.

The apparatus employed by Faraday in investigating the question of specific conducting powers was a kind of Leyden phial: it is shown in

section in Fig. 15; *a a* are the two halves of a brass sphere with an air-tight joint at *b*; *c* is a connecting piece, by which the apparatus is joined to a good stop-cock *d*, which is itself attached either to the metallic foot *e*, or to an air-pump; *g* is a brass collar, fitted to the upper hemisphere, through which the shell-lac support of the inner brass ball *h* passes. This ball is screwed on to the brass stem *i*, terminating above by the brass ball B; *l l* is a mass of shell lac moulded carefully on to *i*, and serving both to support and insulate it and its balls *h* B.

Fig. 15.



The shell-lac stem *l* is fitted into the socket *g* by a little cement more fusible than shell lac, applied at *m*, *m*, in such a way as to give sufficient strength and render the apparatus air-tight there, yet leave as much as possible of the lower part of the shell-lac stem untouched as an insulation between the ball *h*, and the surrounding sphere *a a*; the ball *h* has a small aperture at *n*, so that when the apparatus is exhausted of one gas, and filled with another, the ball *h* may also be exhausted and filled, that no variation of the gas in the interval *o* may occur during the course of an experiment.

Two of these instruments, precisely similar in every respect, were constructed, and the method of experimenting was (different insulating media being within) to charge one with a Leyden phial; then, after dividing the charge with the other, to observe what the ultimate conditions of each were, the intensity of the charge being measured by a carrier ball and Coulomb's electrometer.

Comparing together various substances by this general method, Faraday and Harris obtained the following values for the specific inductive capacities of the bodies named:—

Specific Induction.

Air	1·00	Glass	1·90
Resin	1·77	Sulphur	1·93
Pitch	1·80	Shell lac	1·95
Bee's-wax	1·86		

All gases have the same inductive capacity, independent of temperature and pressure.

(11) **Electricity resides on the surface of electrified bodies.**—When a body receives a charge of electricity, the charge does not, as in the case of heat, diffuse itself throughout the whole of its substance, but is confined entirely to its surface; from this it follows that a metallic ball may be equally electrified whether it be solid or hollow; and that if it be hollow, the amount of electricity will be the same, whether the shell of matter of which it is composed be thick or thin.

1. Let A B be an insulated cylinder, movable round a horizontal axis,

which may be turned by the glass handle H. Round this cylinder let a metallic ribbon, C D, be wound, and let a silk cord, F, be attached to the end of it. Let a pith-ball electroscope, E, be fixed on the metallic frame of the apparatus. The ribbon being electrified, the pith-balls diverge: let it now be unrolled by pulling the silk cord; the balls will gradually collapse, indicating a diminution of the electrical charge; and if the ribbon be sufficiently long, compared with the electrical charge given to the apparatus, they will fall almost entirely together, but will again diverge on re-rolling the ribbon on the cylinder.

Fig. 16.

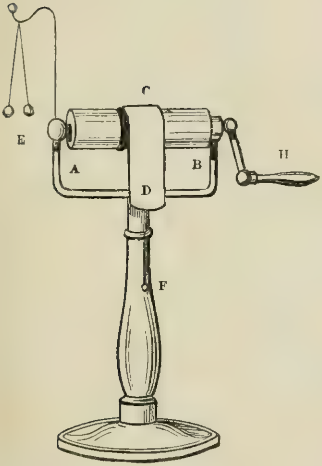
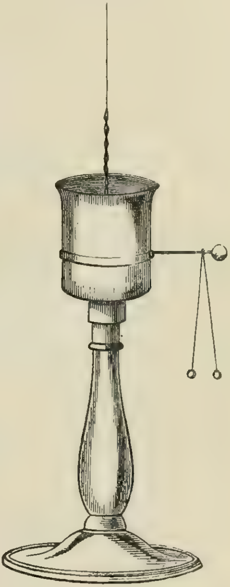


Fig. 17.



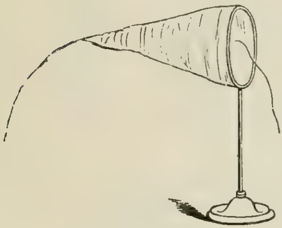
2. Let a metallic cup be placed on a varnished glass support, and let a metallic chain, terminated by a silk thread, be coiled up and placed in its interior, Let the cup be electrified; upon which the pith-balls, hung from a metallic wire attached to the cup, will diverge to a certain extent. Now let the chain be drawn gradually out of the cup by the silk thread; the divergence of the balls will lessen, and finally will become scarcely perceptible. On now again dropping the chain gradually into the cup, the balls will again begin to diverge, and the divergence will increase till the whole of the chain has been returned, when it will be nearly as great as at first.

3. Place a cylinder of wire gauze on an insulated stand, and communicate a small charge of electricity to its *inner* surface. Try now to remove a portion of this charge for testing, by touching the inner surface with a proof-

plane (which is merely a disc of gilt pasteboard attached to a stick of shell lac), the electroscope will show no signs of electricity; then touch the *outside* of the guaze with the proof-plane, and abundant evidence of electricity will be obtained.

4. A conical muslin bag, stiff enough to preserve its form, is attached to a metallic hoop, insulated, on a varnished glass rod, and placed in a horizontal position, as shown in Fig. 18; a charge of electricity is conveyed to the *interior* of the bag; as in the last experiment, the whole is found arranged on the outside of the cone: the cone is now drawn inside out by means of a silk thread, so that the surface of the muslin, which before formed the *inner*, now forms the *outer* superficies. On applying the proof-plane, it is found that the charge has passed from one surface of the muslin to the other, in order still to be on the outside.

Fig. 18.



Faraday constructed a light wooden chamber of 12 feet cube, which he bound round with copper wire, so as to make the sides a large network; all was then covered with paper, placed in close connection with the wires, and supplied in every direction with bands of tin foil, that the whole might be brought into good metallic communication, and rendered a free conductor in every part. Faraday entered this chamber, which was insulated and put into communication with a powerful electric machine; he used lighted candles, delicate electroscopes, and other tests of electricity, but could find none with the cube, though all the time large sparks and brushes were darting off from every part of the outer surface.

'The conclusion,' says Faraday, 'that I have come to is, that non-conductors, as well as conductors, have never yet had an absolute and independent charge of one electricity communicated to them; and that, to all appearance, such a state of matter is impossible.' (*Ex. Research.* series xi. 1173-4.)

(12) **Distribution of Electricity on the Surfaces of Electrified Bodies.**—Although electricity is confined to the surfaces of bodies, its *intensity* is not on every part the same, except in the case of a sphere, on which the symmetry of the figure renders the uniform distribution of the electricity inevitable. If the body be an oblong spheroid, the intensity is great at the poles, but feeble at the equator. If the body be of a cylindric or prismatic form, a still more rapid augmentation takes place at the extremities, the more so as the length bears a greater proportion to the breadth.

Coulomb insulated a circular cylinder two inches in diameter and thirty inches in length, of which the ends were hemispherical; and, on comparing the quantities of electricity collected at the centre, and at points near the extremities, he obtained the following results. At two inches from the extremity the electricity was to that at the centre as $1\frac{1}{4}$ to 1; at one inch from the extremity it was as $1\frac{4}{5}$ to 1; and at the extremity it was as $2\frac{3}{10}$ to 1.

From the observations of the same philosopher, it appears that the depth of the electric fluid on a conductor increases in rapid proportion on approaching the edges; that the effect is still more augmented at corners, which may be regarded as two edges combined, and that the effect is still further increased if any part of a conductor have the form of a point.

The force which retains electricity on the surface of a conductor was assumed by Coulomb to be the pressure of the atmosphere; and the reason why it is impossible to accumulate any charge on a conductor furnished with points, is because the depth of electricity is there so much increased that the force of the electric fluid exceeds the restraining power of the atmosphere.

But it has been shown by Harris (*Phil. Trans.* 1834) that an electrified ball insulated under the receiver of an air-pump, and connected with an electroscope, undergoes no change by withdrawing $\frac{59}{60}$ths of the air; also, that a charged electroscope enclosed in an air-tight bulb, and placed under a receiver, retains its charge unaltered when $\frac{69}{70}$ths of the air are withdrawn; and that the divergence of a well-insulated gold-leaf electroscope does not diminish when the air in the receiver under which it is placed is exhausted till only $\frac{1}{300}$th part remains.

Again, Faraday has shown that the distribution of electricity on the surface of an insulated sphere is only uniform as long as it is surrounded by a dielectric of the same specific inductive capacity (10); for, when an electrified ball is surrounded partly by air and partly by sulphur or lac, the electricity is diffused on it unequally, though the pressure of the air remains unchanged.

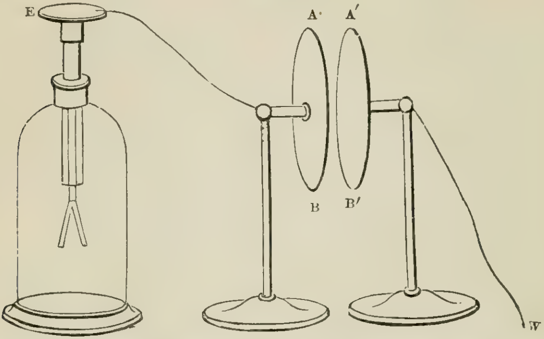
According to Faraday's view of induction—

'An electrified cylinder is more affected by the influence of surrounding conductors at the ends than at the middle, because the ends are exposed to a greater sum of inductive forces than the middle; and a point is brought to a higher condition than a ball, because, by relation to the conductors around, more inductive force terminates on its surface than on an equal surface of the ball with which it is compared.' (*Ex. Research.* xii. 1302.)

(13) **The Condenser.**—When an uninsulated conductor is brought into close proximity to an electrified insulated conductor, the latter acquires an increased electrical capacity, in consequence of the reciprocal inductive actions of the two conductors. On this principle a very important electrical instrument was invented by Œpinus, and introduced into electrical science by Volta, for rendering evident very minute traces of electricity.

Let A B represent a metallic disc insulated on a varnished glass rod, and connected by a wire with the cap, E, of a gold-leaf electroscope, and let A′ B′ represent a similar disc in free communication with the earth by the wire W. Let a feeble charge of electricity be communicated to A B; it will be diffused over E, and the gold leaves of the electroscope will diverge to a certain extent. Let A′ B′ be now caused to approach A B: as it draws near, the

Fig. 19.



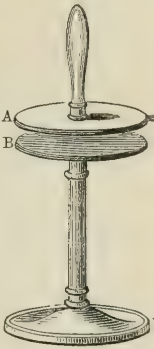
gold leaves will gradually collapse, and when the discs are almost in contact, the charge will be so far withdrawn from E, and concentrated on A B, that the leaves will hang nearly parallel. Let A′ B′ be now suddenly withdrawn to a distance; the electricity accumulated on A B, being now relieved from the inductive influence of A′ B′, will, in virtue of its expansive power, return and diffuse itself over E, the gold leaves of which will immediately return to their former state of divergence.

Suppose the small charge of electricity communicated in this experiment to A B to be *positive*, it decomposes the natural electricity of A′ B′, repelling the *positive* or attracting the *negative*; the greater portion of the positive electricity with which A B was charged is therefore concentrated on the surface of the plate immediately opposed to A′ B′; it is there masked, and for the time neutralised; the effect on the electroscope is reduced almost to nothing, and to affect the leaves in the same manner as before an additional quantity of positive electricity is required: none of the charge communicated to A B is, however, lost, for when the opposing compensating plate is removed, the whole becomes free, it diffuses itself over the entire conducting system, and the electroscope is influenced by the united forces of both charges. In this way, charges of electricity too feeble to produce a divergence of the leaves of the electroscope by direct contact may be rendered sensible, hence the name of *condenser* given to the instrument.

The original condenser of Volta consisted of two large circular

metallic discs, the surfaces of which were covered with a thin uniform coating of amber varnish; the lower disc, B, the condenser, was supported on a metallic stand, B B; the upper disc, A, called the *collector*, was provided with an insulating handle, and a short wire terminating in a metallic ball, E. The body the electricity of which was to be investigated was brought into contact with E; the electricity thus communicated to A, acting by induction on B, confined the electricity of the opposite kind, repelling its similar electricity; at the same time, B, being in perfect electrical communication with the earth, had a constant supply of neutral electricity conveyed to it, which in its turn underwent a similar decomposition. This process lasted until the condenser had received the full charge answering to its surface. The collector, A, being suddenly raised by its insulating handle, taking care to keep it parallel to the base, the electricity accumulated upon it could be transferred to an electroscope for examination. The plates may be placed vertically, and if made a foot or more in diameter are very efficient.

Fig. 20.



For the sake of convenience, however, it is usual to attach both condenser and collector to the gold-leaf electroscope, as shown in Fig. 19.

(14) **Laws regulating the Inductive Actions of the Discs.**—These, and the operation of the direct and reflective inductive forces, have been investigated by Harris (*Phil. Trans.* 1834). The quantity of electricity displaced from A′ B′ may be considered as the direct induction of the plate A B. Harris measured the force of this induction at varying distances between the plates by means of his *hydrostatic electrometer* (*Phil. Trans.* 1839), an instrument constructed by him for measuring directly the attractive force of an electrified body in terms of a standard weight. He found—

1. That the inductive forces are *inversely as the squares of the distances between the plates*; and as the quantity of electricity is as the *square root* of the forces, the direct induced force is *inversely as the distance.*

2. That the distances between the plates being constant, and the quantity of electricity varied, the induced force is as the exciting electricity *directly*, and as the distance *inversely.*

That when A′ B′ is insulated, then the direct induction is no longer as

before, in the simple inverse ratio of the distances, but in the *inverse ratio of the square roots* of the distances.

Then as regards reflected induction of A′ B′ on A B, he found—

1. That when A′ B′ was uninsulated the force was in the *inverse ratio* of the distances between the plates.

2. That when A′ B′ was insulated the variation was as before, in *the inverse ratio of the square roots* of the distance.

(15) **Varley's Multiplier**.—An exceedingly ingenious instrument, by which very feeble electrical tensions may be multiplied several thousand fold, so that by its use the tension of the feeblest electrical sources may be demonstrated, and sparks or other analogous phenomena developed from a tension no greater than that produced by a single cell of the voltaic battery, was exhibited at the International Exhibition of 1862 by Mr. Varley. (*Jurors' Report.*)

This instrument might be called a multiplying indicator. It consists of an axis, on which parallel rows of insulated brass vanes or arms are fixed. The description will be simplified by considering one row of vanes only: A, B, C, D, &c. The axis may be turned by hand, and at two points of the revolution, diametrically opposite to each other, the vanes enter two rows of hollow insulated coverings or shells of brass, a, a_1, a_2, a_3, &c., and b, b_1, b_2, b_3, &c. These shells conceal the vanes entirely on the three sides, and are connected one with another as follows:—a unconnected, a_1 a_2 joined together, a_3 a_4 joined together, a_5 a_6 joined together, &c. In the opposite row, b b_1 are joined, b_2 b_3 joined, b_4 b_5 joined, &c.; a is opposite to b; a_1 opposite to b_1, &c. Thus the two rows may be said to be arranged in alternate insulated couples.

The charge to be multiplied is communicated to a, and we will suppose this charge to consist of a certain definite quantity retained without loss by means of perfect insulation. The axis is turned round by hand. When the vane A is inside a, an earth connection is made at the inner end of the vane A, where it is not covered by the shell. If the charge on a be positive, a *negative* charge of corresponding magnitude will be induced on A. The charge so induced may approach more or less nearly, according to the proportions of the instrument, to equality on the charge on a; it will always be somewhat less, but can easily be made in practice to differ very little from the original charge. When the axis is turned round still further, the earth connection is broken, and the negative charge remains insulated on the vane A. As the axis continues to revolve, the vane A is brought inside the shell b, and is then put in connection with shells b b_1 by a suitable contact. The negative charge on A will then almost entirely distribute itself over the

outer surface of the double shell $b\,b_1$. As the axis is turned round and round, the same series of contacts will be repeated, successive charges on A will be induced by a, and communicated to the double shell $b\ b_1$, on the surface of which these charges will gradually accumulate, tending towards a limit which is only not infinite (leaving insulation out of consideration), because when the vane is inside $b\ b_1$, and its contact there made, its whole metal is not surrounded by a closed metal surface forming part of b. The effect will, however, practically be rather limited by imperfect insulation than by the want of continuity in the surrounding surface of $b\,b_1$. But while negative electricity is thus accumulating on $b\ b_1$, the second vane, B, has been continually passing through the shell b_1. At the moment when fully covered by this shell, an earth contact has been made with this vane, as already described for vane A. B has therefore been receiving continually greater charges of *positive* electricity, each very nearly equal to the quantity of negative electricity at that time on $b\,b_1$, and these in their turn it has communicated to the shells $a_1\,a_2$. The vane C receives continually increasing negative charges from $a_1\ a_2$, which it communicates to $b_3\,b_4$, and thus the multiplication proceeds through any required number of vanes and shells, by the simple process of turning the axis.

If all the vanes and shells be alike, and if one vane with its pair of shells can at most produce a charge in the second shell only ten times greater than that in the first, it is clear that ten vanes and their shells would produce a maximum charge in the final shell 10^{10}, or 10,000,000,000 times greater than on the first shell. The tension of this final shell, if all disturbing causes be removed, would likewise be 10,000,000,000 times greater than that of the first shell under similar circumstances. Metallic screens in connection with the earth are used between each pair of coupled shells to prevent their action one on the other, and also surrounding the whole apparatus to screen it from irregularity.

As a proof that this instrument can be relied on as indicating a real multiplication of the charge originally given to the first plate, Mr. Varley showed to the Jury a strong positive tension of the positive pole of a single Daniell's voltaic cell, by a definite number of rotations of the axis; and then, reversing the poles of the battery, and turning the axis of the instrument *double* the number of times used to produce the first tension, he reversed that tension, and produced a very nearly equal tension of the opposite kind. The tensions were strong enough to produce sparks.

Mr. Varley states that he has obtained a multiplication of more than 15,000 times the original tension by the use of this instrument.

CHAPTER III.

FRICTIONAL ELECTRICITY (*continued*).

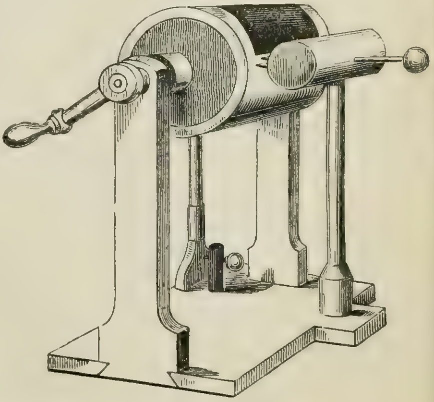
Apparatus for Exciting and Accumulating Electricity.

(16) **The Electrical Machine**.—The first apparatus that was constructed for the exhibition of electrical phenomena, to which the name of *electrical machine* was given, was the globe of sulphur used by Boyle and Otto Guericke. The substitution of glass for sulphur was made by Newton, the rubbers in both cases being the hand. That important part of the machine called the *prime conductor* was first introduced by Boze; it consisted of an iron tube suspended by silken strings; and the substitution of a cushion for applying friction in the place of the hand was first made by Winkler.

The electric of the modern electrical machine is generally glass, and the form either a cylinder or a plate; discs of gutta-percha and ebonite are also employed; and it has recently been proposed to return to sulphur, a disc of which, a metre in diameter and two or three centimetres thick, makes, according to M. Richer (*French Academy of Sciences*, Jan. 30, 1865), an excellent machine.

The glass cylindrical electrical machine is shown in Fig. 22.

Fig. 21.



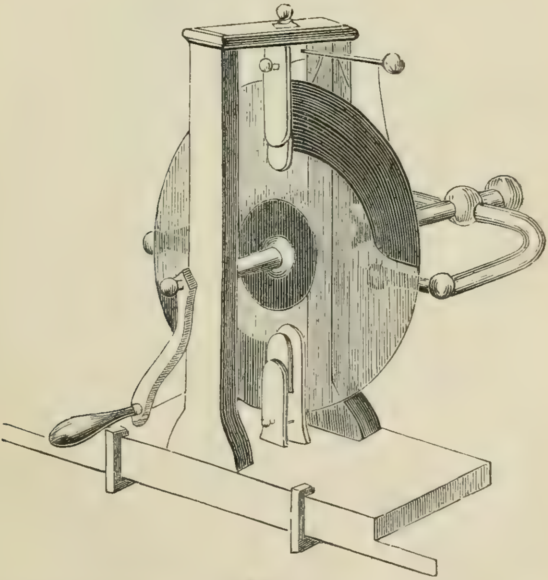
It consists of, 1, a hollow cylinder of glass supported on brass bearings which revolve in upright pieces of wood attached to a rectangular base; 2, a cushion of leather stuffed with horse-hair, and fixed to a pillar of glass, furnished with a screw to regulate the degree of pressure on the cylinder; 3, a cylinder of metal or wood covered with tin foil, mounted on a glass stand, and terminated on one side by a series of points, and on the other side by a brass ball. A flap of oiled silk is attached to the rubber to prevent the dissipation of electricity from the surface of the cylinder before it reaches the points.

The surface of the leather cushion is smeared with a metallic amalgam, made by melting together five parts of zinc and three parts of tin, and pouring gradually on the melted mixture nine parts of metallic mercury previously warmed: the whole is shaken briskly till cold, in an iron or thick wooden box; it is then reduced to a fine powder in a mortar, sifted through muslin, and mixed with lard in sufficient quantity to reduce it to the consistency of paste. This preparation should be spread cleanly over the surface of the cushion, up to the line formed by the junction of the silk flap with the cushion. By the use of this amalgam electrical excitation is greatly promoted.

The glass plate electrical machine is shown in Fig. 22.

It consists of a circular plate of thick flinty glass, revolving vertically by means of a winch between two uprights. Two pairs of rubbers, formed of slips of elastic wood covered with leather, stuffed with horse-hair, and

Fig. 22.

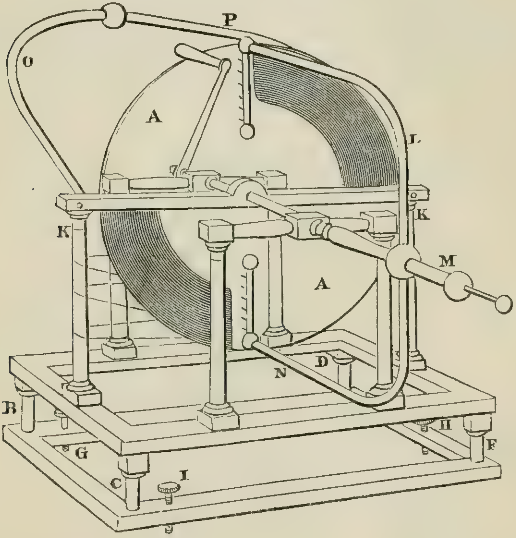


furnished with silk flaps, are placed at two equidistant portions of the plate, on which their pressure may be increased or diminished by means of brass screws. The prime conductor consists of hollow brass, supported horizontally from one of the uprights: its arms, where they approach the plates, being furnished with points.

Sir William Snow Harris's arrangement of the plate electrical machine is shown in Fig. 23.

The plate A A, about three feet in diameter, is mounted on a metallic axis resting on two horizontal supports of mahogany, which are themselves sustained by four vertical mahogany columns, fixed upon a firm frame as a base. The whole apparatus rests on the four legs B C D F, and these again rest upon another steady frame, provided with three levelling screws, G H I, for securing it in a horizontal position. The rubbers are insulated on the

Fig. 23.



glass pillars K K, one on either side of the horizontal diameter of the plate. L M N is the positive conductor, projecting in a vertical position in front of the plate; while the negative conductor, O P, passes in a curvilinear direction behind, and connects the rubber of each side.

The glass plate is turned by an insulated handle, immediately in front of which is placed a short index, which is fixed to the axis, and which moves over a graduated circle attached to the horizontal part of the frame, and through the centre of which the axis passes. In this mannar the number of revolutions of the plate may be accurately registered.

The machine used by Faraday in his famous researches is somewhat similar in construction to the above. The plate is 50

inches in diameter, and the metallic surface of the conductor in contact with the air about 142·2 square inches. When in good excitation, one revolution of the plate will give ten or twelve sparks from the conductor, each an inch in length, and sparks or flashes from 10 to 14 inches in length may easily be drawn from the conductor.

A magnificent plate electrical machine was many years ago constructed for the late Panopticon of Science in Leicester Square. The plate of this machine was *ten feet* in diameter: it was turned by steam power, and excited by three pair of rubbers, each pair nearly 3 feet in length. The conductor was pear-shaped, 6 feet in length, and 4 feet in diameter at its widest part. When well excited, sparks from 15 to 18 inches in length, and of remarkable brilliancy and volume, could be drawn from the terminal ball of the conductor, and a battery of thirty-six jars, presenting 108 square feet of coated glass, could be charged to saturation in less than one minute.

(17) **Relative merits of the Cylinder and Plate Electrical Machine.**—Cylinder machines have, according to Hearder (*Phil. Mag.* vol. xv. p. 290), a superiority in their exciting power over plate machines of equal surface in the proportion of 4 to 1, and are for ordinary experimental purposes much more convenient. A cylinder of 12 inches in diameter, having a single rubber of 9 inches in length, is equal to a 24-inch plate machine having four rubbers each $5\frac{1}{2}$ inches long. In very large plate machines, where a single pair of rubbers only is used, the sacrifice of power, in proportion to the size of the machine, is very great, and the only advantage which they appear to possess as a compensation for this loss is that of affording very long sparks from a large conductor.

A well-constructed machine, having a cylinder 32 inches in circumference, and a rubber 9 inches in length, with a prime conductor 4 or 5 inches in diameter and 20 inches long, should, without the necessity of warming the cylinder, give four to six dense sparks of 3 to $3\frac{1}{2}$ inches in length for every revolution of the cylinder. A 2-inch ball inserted into the conductor should throw off spontaneously rapid brushes of electricity into the air, and furnish zigzag sparks of 9 inches or more in length; it should also charge a Leyden phial of ordinary thickness, containing 4 square feet of internal surface, so as to discharge at 0·5 of an inch with 48 or 50 turns.

The best material for the flap attached to the rubber, is, according to the same authority, thin yellow oiled silk; it should be varnished on one side only, the unvarnished side being applied to the glass to prevent adhesion. If both sides of the silk are var-

nished, that side which is to be applied to the glass should be prepared by giving it two or three coatings of shell-lac varnish. As a great desideratum is the close approximation of the flap with the cylinder, the common practice of sewing the silk flap to the upper end of the rubber is objectionable; it should be attached to the lower end, and allowed to pass up between the rubber and the cylinder. In order to prevent the injury which would accrue to the flap from repeatedly spreading the amalgam upon the surface which covers the rubber, a second piece of unoiled silk is attached to the lower end of the rubber and turned up over its face so as to receive the amalgam; when torn, it may easily be replaced. The silk flap should extend over one-fourth of the circumference of the cylinder.

The substitution of discs of *ebonite* for those of glass in the plate electrical machine, and of conductors mounted on ebonite stems, gives excellent results, allowing the apparatus to be worked satisfactorily in damp states of the atmosphere, when instruments made with the common glass mountings would be nearly useless. At the International Exhibition of 1862, Mr. C. F. Varley exhibited a machine, the ebonite disc of which was 35 inches in diameter. A large induction ring was used with this machine, on the plan recommended by Dr. Winter, of Vienna. Under favourable circumstances, sparks 20 inches in length could be obtained from Mr. Varley's instrument. Without Dr. Winter's ring the sparks are reduced to about 7 inches.

The amalgam used with ebonite should be softer than that used with glass, otherwise the disc deteriorates with use.

(18) **Theory of the Electrical Machine.**—The theory of the action of the electrical machine flows immediately from the principles of induction already illustrated (7). On turning the handle, the natural electricity of the rubber becomes by friction disturbed, the positive fluid adhering to the surface of the glass, and the negative to the rubber. The positive electric portions of the glass, coming, during its revolution, opposite to the points on the conductor, act powerfully by induction on the latter, attracting the negative, which, being accumulated in a state of tension at the points, darts off towards the cylinder to meet the positive fluid, and thus re-constitute the neutral compound: the consequence is, that the conductor is left powerfully positive, and the rubbers proportionately negative, and after a few revolutions of the glass no more free positive electricity can be developed, provided the rubbers are insulated. It is therefore necessary to put them into conducting communication with the earth, whereby a sufficient supply of positive electricity is obtained to neutralise its negative state. In very

dry weather it is necessary to connect the rubbers with the moist earth by means of a good conductor; and it is advisable, if possible, to establish a metallic connection with the metallic water pipes.

On presenting to the prime conductor the knuckle, or a conducting body in electrical communication with the earth, a vivid spark passes between them, accompanied by a sharp snapping sound. It is usual to speak of this spark (in the case of a glass electrical machine) as the *positive spark*: a term which, according to the electrical theory now generally adopted, does not convey a correct idea of its nature. According to the principles of induction (7), the free positive electricity on the prime conductor disturbs the neutral electrical condition of a neighbouring and passive conductor, drawing the negative fluid towards itself, and repelling the positive; and when this state has amounted to one of sufficient *tension*, the negative electricity rushes towards the positive electricity of the conductor. It is this neutralisation or discharge of the electric state of the conductor which constitutes the spark.

If, instead of connecting the rubbers with the earth, they are left insulated, and the prime conductor uninsulated, then sparks will pass between the rubbers and a conducting body in electrical communication with the earth; and if both rubbers and prime conductor be insulated, but connected together by a metallic wire, no trace of electricity can be obtained from any part of the machine. Thus, in order to get any development of electricity, there must be, either with the rubber or with the prime conductor, electrical communication with the earth as the great natural reservoir of electricity.

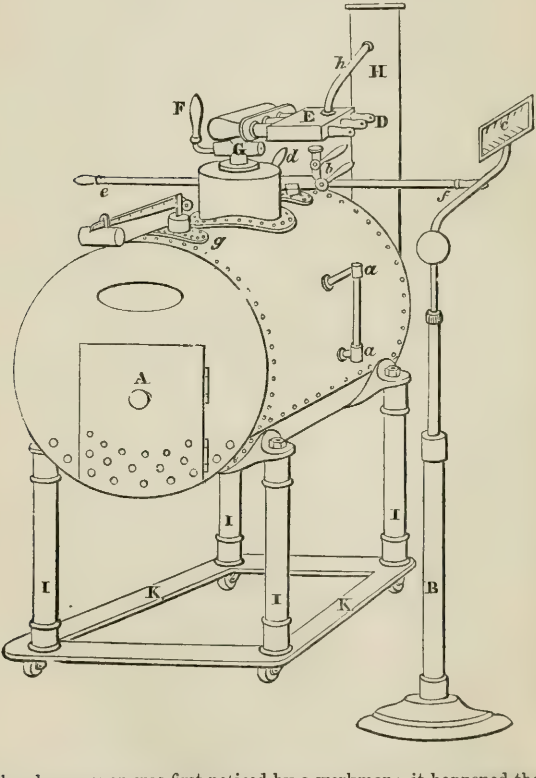
With regard to this Professor Fleeming Jenkin remarks:—

'This induction of electricity must take place in the space surrounding every electrified body. In a room containing a ball electrified positively, the surface of the walls, the furniture, the experimenter himself, must necessarily all be charged negatively in virtue of their induction. Where does this negative electricity come from? If the electrified body has been charged positively by rubbing, and the negative electricity has been allowed free access to the earth, it may be said that this negative electricity has been attracted to the surface of the walls, furniture, &c., distributing itself according to definite laws which must be separately studied. If both rubber and glass have been insulated, then each induces on all surrounding surfaces positive and negative electricities equal each to each, but these induced quantities are now not necessarily equal to the amount on the glass or on the rubber, unless these be removed very far apart from one another. If the two oppositely electrified bodies are kept close together, their inductive actions are spent almost entirely on each other, and their action on the surrounding walls of the room is almost nothing, for where the one tends to induce a positive charge the other tends to induce a negative charge; as the insulated electrified bodies are removed farther apart, each produces its independent effect more completely.' (Jenkin, *Electricity and Magnetism.*)

(19) **The Hydro-Electric Machine.**—Under the head of Frictional Electricity must be included the remarkable source of development by *effluent steam*, which, in the hands of Faraday, Armstrong, Ibbetson, and others, has led to the construction of machines capable of producing electricity in enormous quantity.

The first account we have of an observation on the electricity of a jet of steam is contained in a letter addressed to Professor Faraday by Mr. (now Sir William) Armstrong (*Phil. Mag.* vol. xvii.)

Fig. 24.



The phenomenon was first noticed by a workman: it happened that the cement by which the safety-valve was secured to a boiler had a crack in it, and through this fissure a copious horizontal jet of steam constantly issued. Soon after this took place, the engine-man, having accidentally one of his

hands immersed in the issuing steam, presented the other to the lever of the valve with the view of adjusting the weight, when he was greatly surprised by the appearance of a brilliant spark which passed between the lever and his hand, and was accompanied by a violent wrench in his arms, wholly unlike anything he had ever experienced before.

A series of experiments instituted by Mr. Armstrong led him to the conclusion that the excitation of electricity takes place at the point where the steam is subjected to friction; and it was subsequently shown by Faraday that the presence of water is necessary, and that in fact the generation of electricity is the result of the friction of condensed particles of water whilst being driven by the issuing steam through the jet from which it escapes.

The hydro-electric machine is shown in Fig. 24.

The boiler is 2 ft. 6 in. in length, and 1 ft. 2 in. in diameter; A is the door of the fire-place; B C, the conductor for collecting electricity from the steam; C, the collecting points; B, a glass insulating stem; D, the escape-tubes and jets, of peculiar construction, and made of partridge wood; E, the condensing vessel enclosing the iron pipes by which the steam is conveyed to the jets The lower part of the condensing vessel contains water, which nearly reaches the lower end of the steam-pipes; from the latter are suspended filaments of cotton, which dip into the water, and by capillary action raise just sufficient to cause, by its action on the pipes, a condensation of the requisite quantity of water for rubbing against the jets; F G is the cock for letting off the steam; H, the chimney; I I I I, the insulating glass pillars; K K, the frame moving on castors; *a a*, the water-gauge; *f e*, condensing pipes for showing the effect of impregnating the ejected water with extraneous substances, and for exhibiting two jets of steam simultaneously, issuing from the boiler in opposite states of electricity; *b*, the cock for introducing extraneous matter; *c d*, cocks for admitting steam to the pipes; *g*, the safety-valve; *h*, the escape-pipe for the vapour of the condensing tube. The fuel is charcoal. When in good working order, a machine of the above size will produce, according to the makers, as much electricity as three 30-inch plate machines.

The electricity produced by the hydro-electric machine is more remarkable for its enormous quantity than for high intensity. A magnificent machine was some years ago constructed for the Royal Polytechnic Institution, under the superintendence of Messrs. Armstrong and Ibbetson. The maximum spark obtained in the open air was 22 inches in length. While working in the lecture-room of the institution the length of the spark rarely exceeded 14 inches, but it was capable of charging 80 feet of coated glass in 6 or 8 seconds, to do which required from a glass plate machine 7 feet in diameter about 50 seconds. A still more powerful machine was constructed for the use of an institution in America. The steam was made to issue through 140 jets. The sparks obtained were not longer than those obtained from the London machine, but they succeeded each other with three or four times the rapidity,

and charged to the utmost degree that it could bear a battery of thirty-six Leyden jars, each containing 33 feet of coated surface, upwards of sixty times in a minute.

(20) **Different forms of Disruptive Discharge.**—The discharge which takes place between two conducting surfaces is termed *disruptive.*

'It is,' according to Faraday's view, 'the limit of the influence which the intervening air or *dielectric* exerts in resisting discharge. It occurs not when all the particles have attained to a certain degree of tension, but when that particle which is most affected has been exalted to the subverting or turning point; all must then give way, since they are linked together, as it were, by the influence of the constraining force, and the breaking down of one particle must of necessity cause the whole barrier to be overturned.'

(*a*) *Spark discharge.*—This may be considered as the destruction, by a convulsive effort, as it were, of the polarised inductive state of many dielectric particles by a particular action of a few occupying a limited space, 'all the previously polarised particles returning to their first or normal condition in the inverse order in which they left it, and uniting their powers meanwhile to produce or rather to continue the discharge effect in the place where the subversion of force first occurred.' (Faraday, *Ex. Research.* 13th and 14th series.)

Several circumstances contribute to exert a marked influence on the character and appearance of the electric spark. If a large uninsulated metallic ball be brought within striking distance of an equal-sized ball attached to the prime conductor of a machine in vigorous action, the sparks are short, straight, brilliant, and sonorous; if the ball attached to the prime conductor be small (an inch or so in diameter), the sparks are no longer straight, but they are much longer and less luminous. They have now a crooked or zigzag appearance, reminding forcibly of that form of lightning

Fig. 25.

called 'forked lightning.' The sparks from the rubber or negative conductor are much shorter and less brilliant than those from the positive conductor.

The electric spark presents different appearances in different elastic media.

In *air* they have, when obtained with brass balls, a well-known intense light and bluish colour, with frequently faint or dark parts in their course, when the quantity of electricity passing is not great.

In *nitrogen* they are very beautiful, having the same general appearance as in air, but more colour of a purple or bluish character.

In *oxygen* they are brighter, but not so brilliant as in common air.

In *hydrogen* they are of a fine crimson colour, but have very little sound in consequence of the physical character of the gas.

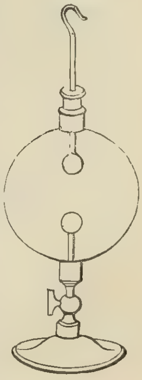
In *carbonic acid gas* they have the same general appearance as in air, but are remarkably irregular. Sparks can be obtained under similar circumstances much longer than in air, the gas showing a singular readiness to pass the discharge.

In *muriatic acid gas*, when dry, they are nearly white, and almost always bright throughout.

In *coal gas* they are sometimes green, sometimes red; occasionally one part is green and another red. Black parts also occur very suddenly in the line of the spark, *i.e.* they are not connected by any dull part with bright portions, but the two seem to join directly the one with the other.—*Faraday*.

The pressure or density of the air exercises a great influence on the spark disruptive discharge. Harris found (*Phil. Trans.* 1834) that the quantities of electricity required to produce discharge across a *constant* interval varied exactly with the variations of density, the quantity of electricity and density of the air being in the same simple ratio. Or, if the quantity retained were the same, whilst the interval and density of the air were varied, then these were found in the inverse simple ratio of each other, the same quantity passing across twice the distance with air rarefied to one half.

Fig. 26.

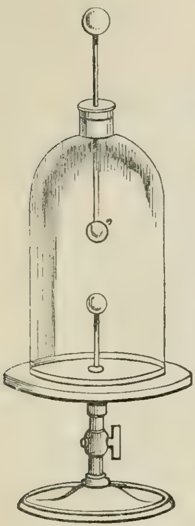


For illustrating the influence of the condensation and rarefaction of air, and for examining the effects of different gases on the colour and appearance of the electric spark, the simple apparatus shown in Fig. 26 may be employed. It consists of a glass globe about four inches in diameter, provided at each end with a brass cap; to one of which a stop cock is screwed, with a wire and ball projecting into the globe, and through the other a similar wire slides through a collar of leather, so that the balls may be set at any required distance from each other in the globe. The apparatus may be exhausted by the air pump, or the air may be condensed in it by a condensing syringe.

The apparatus shown in Fig. 27 may also be used for performing some striking experiments. The receiver having been exhausted is screwed on a transfer plate, which is connected by a wire with

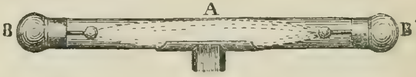
the negative conductor: the upper ball being connected with the positive. The balls should be set at a distance of about 5 or 6 inches apart. On turning the machine a current of beautiful light passes from the positive to the negative ball, on which it breaks and divides into a luminous atmosphere, entirely surrounding the lower ball and stem; and conveying in a striking manner the idea of a fluid running over the surface of a resisting solid, which it cannot enter with facility. No appearance of light occurs on the positive ball, but the straight luminous line that passes from it. If, however, it be rendered negative and the lower ball positive, these effects are reversed.

Fig. 27.



Let a glass tube, two or more feet long and furnished at either end with a brass ball projecting into its interior, be well exhausted of its air; let B be connected with the prime conductor and B′ with the earth, when the machine is turned, induction taking place with increased facility in consequence of the rarefaction of the air, discharge takes place through the tube filling it with a beautiful blue light, closely resembling the aurora borealis.

Fig. 28.



Spark discharge, immediately following exalted induction, is beautifully illustrated by the 'magic pane,' which is merely a plate of glass on which are pasted some strips of tin foil, having portions cut out so that the space represents letters as shown in the figure. On connecting the first piece of foil with the conductor and the last with the ground, the letters will appear in characters of fire in consequence of luminous discharge taking place, apparently at the same moment, across all the open spaces. In a similar manner lozenge-shaped pieces of tin foil may be arranged spirally round a glass tube, 3 or 4 feet long; a beautiful spiral line of sparks is produced, on bringing one end of the tube within striking distance of the prime conductor and holding the other end in the hand.

Fig. 29.

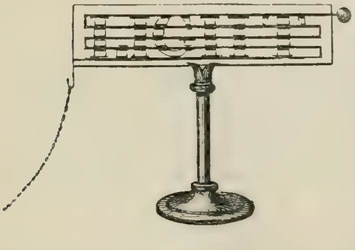
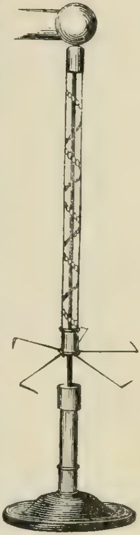


Fig. 30 represents an arrangement for exhibiting the revolution of a spotted tube. It is made of a glass tube, blown smooth and round at one end and open at the other: it should be about ten inches long

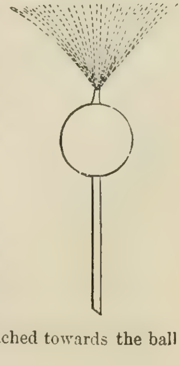
and three-quarters of an inch in diameter. A ball or piece of smooth tin-foil is fixed on the upper closed end, and the usual spots of foil carried in a spiral form to the lower open end. A cap, either of wood or brass, is cemented on the outside of the lower end of the tube, from which four wires project outwards, having their points bent at right angles. The tube is then set on an upright wire which passes upwards into the tube to its top, and this wire is then set on an insulated stand and brought near the prime conductor. It can thus revolve with great ease.

Fig. 30.



(*b*) *Brush discharge.*—This has been shown by Wheatstone to consist of successive *intermitting* discharges, although it appears continuous. It is in reality a discharge between a bad or a non-conductor, and either a conductor or another non-conductor. According to Faraday it may be considered as a *spark to air*; a diffusion of electric force to matter, not by *conduction*, but by disruptive discharge. He explains the phenomenon on the principle of induction, which, taking place between the end of an electrified rod and the walls of a room across the *dielectric* air, polarises the particles of air; those which are nearest to the end of the wire being most intensely polarised, and those situated in sections across the lines of inductive force towards the wall being least polarised. In consequence of this state, the particle of air at the end of the wire is at a tension that will immediately terminate in discharge, while in those even only a few inches off the tension is still beneath that point. When discharge takes place the particle of air in the immediate vicinity of the rod instantaneously resumes its polarised state; the wire itself regaining *its* electrical state by induction, the polarised particle of air exerts a distinct inductive act towards the further particles, and thus a progressive discharge from particle to particle takes place.

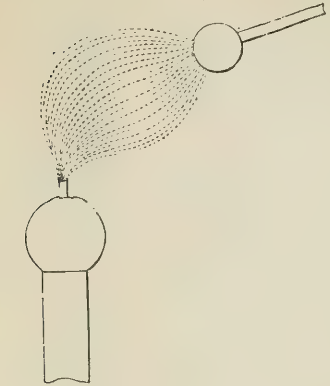
Fig. 31.

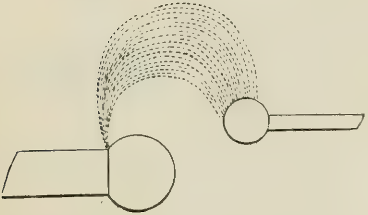


The general appearance of a good brush is represented in Fig. 31. It may be thus produced by attaching to the prime conductor of a powerful electrical machine a long brass rod terminated by a brass ball about 0·7 of an inch in diameter. If the machine be not in very good action, many ways of assisting the formation of a brush may be resorted to: thus the hand or any large conducting surface may be approached towards the ball

to increase the inductive force; or the terminal ball may be smaller, and of badly conducting matter, such as wood; or (which gives to the brushes exceedingly fine characters and great magnitude) the air round the termination may be rarefied, more or less, either by heat or the air pump.

Fig. 32.



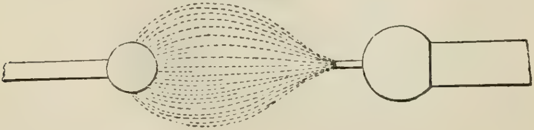


By making a small ball positive by a good electrical machine with a large prime conductor, and approaching a large uninsulated discharging ball towards it, very beautiful variations from the spark to the brush may be obtained. Figs. 32, 33, 34 represent the various forms assumed by the brush on bringing a knobbed conductor into different positions near the discharging ball; the curvature of the ramifications illustrating in a beautiful manner the curved form of the lines of inductive force existing previous to discharge, in the same manner as iron filings strewed on a sheet of paper placed over a magnet represent magnetic curves.

Faraday found that, like the spark, the brush has *specific characters* in different gases. In *nitrogen* they could be obtained with far greater facility than in any other gas, and when the gas was rarefied they were exceedingly fine in form, light, and colour; in *oxygen*, on the other hand, they were very poor.

Brush discharge is accompanied with a low, dull, chattering sound. The general brush is resolvable into a number of individual brushes, each of which is the result of a single discharge, and the sound is due to the recurrence of the noise of each separate discharge.

Fig. 34.



(*c*) *Glow discharge.*—When a fine point is used to produce

disruptive discharge from a positively charged conductor, the brush gives place to a quiet phosphorescent continuous glow covering the whole end of the wire and extending a small distance into the air. Glow discharge, like brush discharge, is always accompanied by a wind proceeding either directly out from the glowing part or directly towards it. It appears to be due to a continuous charge or discharge of air.

Occasionally glow takes the place of brush when a rounded wire 0·3 of an inch in diameter is used, and the finer the point the more readily is it produced. It is surprisingly favoured by rarefaction of the air. A brass ball about 2½ inches in diameter, when made positive in an air pump receiver, becomes covered with a glow over an area of two inches in diameter when the pressure is reduced to 4·5 inches of mercury. By a little adjustment Faraday succeeded in covering the ball all over with this light: using a brass ball 1·25 inch in diameter, and making it *inducteously* positive by an *inductric* negative point, the phenomena at high degrees of rarefaction were exceedingly beautiful. The glow came over the positive ball and gradually increased in brightness until it was at last very luminous, and stood up like a low flame, half an inch or more in height.

On touching the sides of the glass jar, this lambent flame was affected, assumed a ring form like a crown on the top of the ball, appeared flexible, and revolved with a comparatively slow motion *i.e.* about four or five times in a second.

(21) **Disruptive discharge at positive and negative conducting surfaces.**—According to Faraday, the effect varies exceedingly under different circumstances. With bad conductors, or with metallic conductors charged intermittingly, the luminous appearance at the end of wire charged *positively* assumes the form of a *brush*, and that at the end of a wire charged *negatively* the form of a *star*, as shown in Fig. 35. But if the metallic points project freely into the air the positive and negative lights differ very little in appearance.

Fig. 35.

1. If a metallic wire, with a rounded termination in free air, be used to produce the brushy discharge, then the brushes obtained when the wire is charged negatively are very poor and small by comparison with those produced when the charge is positive.

2. If a large metal ball connected with the electrical machine be charged *positively*, and a fine uninsulated point be gradually brought towards it, a star appears on the point when at a considerable distance, which, though it becomes brighter, does not change its form of star until it is close up to the ball; whereas, if the ball be charged *negatively*, the point at a considerable distance has a *star* on it, as before, but when brought within about 1½ inch

a *brush* forms on it, and when still nearer (at $\frac{1}{8}$ of an inch distance) the brush ceases and bright sparks pass.

The successive discharges from a rounded metallic rod 0·3 of an inch in diameter projecting into the air are, when the rod is charged *negatively*, very rapid in their recurrence, being seven or eight times more numerous in the same period than those produced when the rod is charged *positively* to an equal degree ; but each brush carries off far less electric force in the former case than in the latter. Faraday also perceived an important variation in the relative forms and conditions of the positive and negative brush by varying the *dielectric* in which they were produced. Generally speaking, when two similar small conducting surfaces equally placed in air are electrified, one positively and the other negatively, that which is negative can discharge to the air *at a tension a little lower* than that required for the positive ball, and when discharge does take place much more passes at each time from the positive than from the negative surface.

CHAPTER IV.

FRICTIONAL ELECTRICITY (*continued*).

The Leyden Phial and Battery—Laws of Accumulated Electricity—Velocity of Electricity—Physiological, Chemical, and Magnetic Effects.

(22) **Discovery of the Electric or Leyden Phial.**—It was in the years 1745 and 1746 that those celebrated experiments which for many years drew the almost exclusive attention of men of science to the subject of electricity were made by Kleist, Musschenbroek, and Cuneus.

Musschenbroek and his associates having observed that electrified bodies exposed to the atmosphere speedily lost their *electric 'virtue,'* conceived the idea of surrounding them with an insulating substance, by which they thought that their electric power might be preserved for a longer time. Water contained in a glass bottle was accordingly electrified, but no remarkable results were obtained till one of the party who was holding the bottle attempted to disengage the wire communicating with the prime conductor of a powerful machine; the consequence was that he received a shock which, though slight compared with such as are now frequently taken for amusement, his fright magnified and exaggerated in a ludicrous manner.

The following is an extract from a letter written by Von Kleist (who appears to have been the real discoverer of the electric phial)

to Dr. Lieberkühn of Berlin, dated Nov. 4, 1745, and communicated by him to the Berlin Academy :—

'When a nail or a piece of brass wire is put into a small apothecary's phial and electrified, remarkable effects follow ; but the phial must be very dry and warm : I commonly rub it over beforehand with a finger, on which I put some pounded chalk. If a little mercury, or a few drops of spirits of wine, be put into it, the experiment succeeds the better.

'As soon as this phial and nail are removed from the electrifying glass, or the prime conductor to which it hath been exposed is taken away, it throws out a pencil of flame so long that, with this burning machine in my hand, I have taken about sixty steps in walking about my room. When it is electrified strongly I can take it into another room, and then fire spirits of wine with it. If, while it is electrifying, I put my finger or a piece of gold which I hold in my hand to the nail, I receive a shock which stuns my arms and shoulders.'

Musschenbroek, in a letter to Réaumur describing the effect produced on himself by taking the shock from a thin glass bowl, says, 'I felt myself struck in my arms, shoulders, and breast. I lost my breath, and it was two days before I recovered from the effects of the blow and the terror.' He adds, 'I would not take a second shock for the kingdom of France.' Allamand, on receiving the shock, declared 'that he lost the use of his breath for some minutes, and then felt so intense a pain along his right arm that he feared permanent injury from it.' Winkler stated that the first time he underwent the experiment 'he suffered great convulsions through his body; that it put his blood in agitation; that he feared an ardent fever, and was obliged to have recourse to cooling medicines.' Such was the alarm with which those early electricians were struck by a sensation which thousands have since experienced in a much more powerful manner without the slightest inconvenience. It serves to show how cautious we should be in receiving the first account of extraordinary discoveries where the imagination is likely to be affected.

(23) **Principles of the Leyden Phial.**—It has been shown (13) that a higher charge may be communicated to the gold-leaf electroscope whilst it is under the influence of an uninsulated conductor. To illustrate this property, we have only to bring the plate A′ B′ (Fig. 19) as close as possible without touching to the plate A B, and communicate a charge to the latter; then on removing A′ B′ the accumulation which has been effected will be indicated by an expansion of the gold leaves considerably beyond the original amount.

When an excited glass tube is brought near to the cap of the electroscope, the second plate (connected with the earth) being close to it, the gold leaves do not open nearly so much as if the

second plate were not there, because induction taking place through the intervening stratum of air to the nearest body, viz. the second or *inducteous* plate, the electricity of the same kind as that with which the cap of the electroscope is charged becomes diffused over the earth (13); but when the second plate is removed, the leaves diverge much more than if it had not been there, because the instrument has received a higher charge. Now in this case the intervening air has received a *higher polar tension*, arising from the close proximity of the charged body to a conductor to the earth, the thinner the intervening stratum of air, the higher the degree of polar tension that may be attained, and the rise of force is limited by the mobility of the particles of air in consequence of which the electrical equilibrium is restored either silently or by a spark.

Now if, instead of a plate or stratum of air, we employ a solid *dielectric*, such as glass or gutta-percha, the tension which may be assumed is limited only by the cohesive force of the dielectric. Thus if we place a plate of glass or a sheet of gutta-percha between two circular pieces of tin, insulate and connect one plate with the prime conductor of an electrical machine, we shall have an arrangement precisely similar to the condenser (Figs. 19 and 20), except that the intervening dielectric is glass or gutta-percha instead of air; on connecting the other plate with the earth to destroy its polar state, and working the machine, the particles of glass will become powerfully polarised; and if instead of connecting one of the plates with the earth we touch it from time to time with the knuckle, a series of sparks will be obtained; after a time these will cease, and on removing the wire connecting the plate with the prime conductor, and insulating the arrangement, that plate will be found to be charged with positive electricity and the other plate with negative. If now both plates be connected by a curved metallic wire, the polar tension of the glass or gutta-percha will be relieved, and *discharge* will occur attended with a vivid spark and a loud snap.

The same effects will be produced by coating both sides of a plate of glass with tin foil, leaving about 1½ inch all round uncovered, and it is quite clear that the *surfaces* of dielectrics and conductors may be arranged in different forms without impairing the effects. Glass jars or bottles are found more convenient in practice than squares of glass. A glass jar or bottle thus coated with tin foil is called a *Leyden jar* in honour of the place of its discovery.

The *quantity* of electricity which may be accumulated in a jar depends upon the extent of the coated surface. The *intensity* depends on the thickness of the glass. But in practice it is found

impossible to diminish the thickness of the glass beyond a certain extent, as the constrained position of its polarised particles is apt to rise so high as to destroy its cohesive force, and the charge breaks its way through the glass.

(24) **Construction of the Leyden Phial—**

Fig. 36 represents a Leyden phial of the usual construction, with the discharging rod furnished with a glass handle in the position in which it is placed in the act of discharging a jar by establishing a metallic communication between the outer and inner metallic coatings. The wire which passes through the varnished mahogany cover of the jar is terminated at one end by a brass ball, and at the other by a chain reaching to the bottom of the jar.

By the construction shown in Fig. 37, the influence of external causes in dissipating the charge of a Leyden jar may, to a considerable extent, be prevented. The jar is coated with tin foil, as usual, but a glass tube, lined internally to rather more than half its length from the bottom and surmounted with a glass cap, is cemented firmly into the wooden cover. A communication is established between the brass cap and the internal coating by a small brass wire, passing loosely through it and terminating in a small knob. The wire touches the inside of the glass tube The jar is charged in the usual manner; the wire may then be removed by inverting the jar; the internal coating is thus cut off from contact with the external air, and the dissipation of the charge prevented. Jars thus arranged have been known to retain their charge for days, and even for weeks.

Fig. 37.

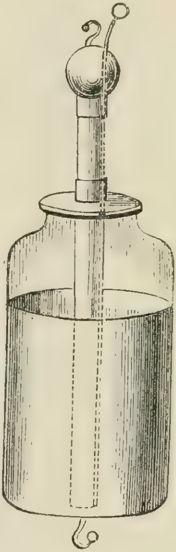
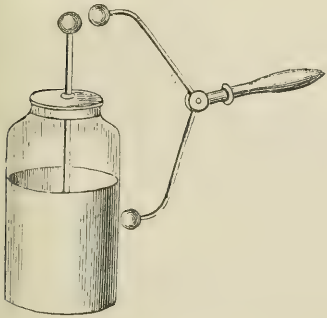


Fig. 36.



Sir W. S. Harris's method of fitting up electric jars is shown in Fig. 38. The mouths are open, and the charge is conveyed to the bottom of the jar by a copper tube, G H, three-eighths of an inch in diameter. This tube terminates in a ball, F, of baked wood, and is kept in its place by a convenient

foot firmly cemented to the bottom of the jar, which is previously covered with a circle of pasted paper, leaving a central portion of the coating free for the perfect contact of the charging rod G H, which passes through the centre of the foot, as shown by the dotted lines in the figure. When the jars are employed singly, they should be placed on a conducting base, supported by short columns of varnished glass, so that if necessary they may be insulated.

Fig. 38.

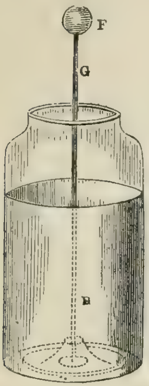
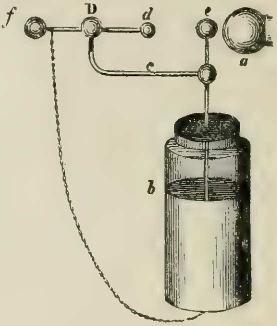


Fig. 39.

Fig. 40.



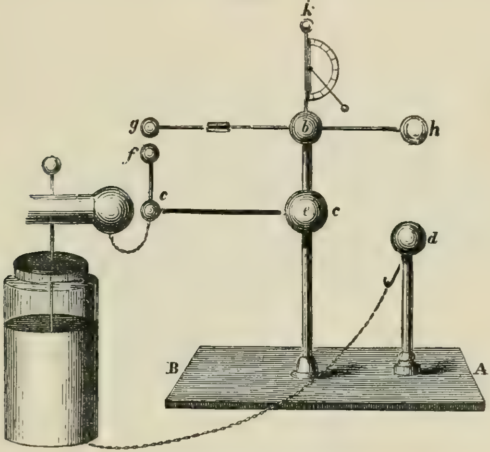
(25) **Charging and Discharging Electrometers.**—The quantity of electricity accumulated in a jar or battery (Figs. 36 and 43) may be roughly estimated by the number of turns of the machine, or more correctly, by the unit jar; its intensity may be determined approximatively by the amount of repulsion between any two movable bodies under its influence.

The instrument shown in Fig. 39 is known as *Henley's Quadrant Electrometer.* It consists of a graduated semicircle of ivory *a*, fixed to a rod of wood *d*. From the centre of *a* a light index of dry straw descends, terminating in a pith-ball, and readily movable on a pin. To use it, it is removed from its stand and fixed in a hole on the top of the ball of the jar, the charge of which it is intended to indicate; as the charge increases the pith-ball moves from its centre of suspension and measures the intensity upon the graduated semicircle.

Fig. 40 represents the apparatus contrived by Mr. Lane for regulating the explosions from a Leyden phial: *a* is the prime conductor, *b* the jar, on the wire communicating with the interior of which is fixed the arm of a bent varnished glass rod *c*, and on the end of this is cemented the brass knob D; through this ball the wire *f d* slides, so that *d* may be brought to any required distance from the knob of the jar *e*. A simple inspection of the figure will show how this discharging electrometer acts, and how by increasing or lessening the distance between *d* and *e* the strength of the charge may be regulated.

Fig. 41 represents *Cuthbertson's Balance Electrometer.* A B is a wooden stand about 18 inches long and 6 broad, in which are fixed two glass supports *d e*, mounted with brass balls; under *d* is a brass hook. The ball *b* is made of two hemispheres, the under one being fixed to the brass mounting, and the upper one turned with a groove to shut upon it, so that it can be taken off at pleasure; it is screwed to a brass tube about four inches long, fitted on to the top of *e*; *g h* is a straight brass wire, with a knife-edged centre in the middle, placed a little below the centre of gravity, and equally balanced with a hollow brass ball at each end, the centre or axis resting

Fig. 41.



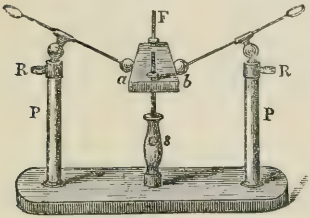
upon a proper-shaped piece of brass fixed in the inside of the ball *b*; that part of the hemisphere towards *h* is cut open to permit that end of the balance to descend till it touches *d*, and the upper hemisphere *b* is also cut open; the arm *g* is divided into sixty divisions, and is furnished with a slider, to be set at the number of divisions which the experiment requires; *k* is a Henley's electrometer screwn upon the top of *b*. The slider is placed loosely on the arm of *g*, so that as soon as *g h* is out of the horizontal position it slides forward towards *b*, and the ascending continues with an accelerated motion till *h* strikes *d*.

Suppose now the instrument to be applied to a jar as in the figure, a metallic communication by a wire or chain is established between *e* and the inside of the jar; *k* is screwed upon *b*, with its index pointing towards *h*; the increase of charge in the jar is thus shown: suppose the slider to be set at fifteen divisions or grains, it will cause *g* to rest upon *f* with a pressure equal to that weight; as the charge increases in the jar the balls *f* and *g* become more and more repulsive of each other; and when this force of repulsion is sufficient to raise fifteen grains, the ball *g* rises, the slider moves towards *b*, and the ball *h* coming into contact with *d* discharges the jar; and as the

force of repulsion depends upon the intensity of the charge, the weight it has to overcome affords a measure of this intensity and enables the experimenter to regulate the amount. Suppose the slider to be set at five grains, and we wish to double the accumulation of electricity in the jar or battery, the slider must be set to twenty grains, the electrical force being the *square* of the quantity of electricity accumulated.

Henley's Universal Discharger.—A very useful apparatus for directing with precision the charge of a jar or battery is shown in Fig. 42. It consists of a wooden stand with a socket fixed in the centre, to which may be occasionally adapted a small table, having a piece of ivory (which is a non-conductor) inlaid on its surface. The table may be raised and kept to a proper height by means of a screw *s*. Two glass pillars, P P, are cemented into the wooden stand. On the top of each of these pillars is fitted a brass cap, having a ring, R, attached to it, containing a joint moving both vertically and horizontally, and carrying on its upper part a spring tube, admitting a brass rod to slide through it. Each of these rods is terminated at one end either by a brass ball *a b* screwed on a point, or by a pair of brass forceps, and is furnished at the other extremity with a brass ring or a handle of solid glass. The body through which the charge is intended to be sent is placed on a table, and the sliding rods, which are movable in every direction, are then by means of the handles brought into contact with the opposite sides; and one of the brass caps being connected with the outside of the jar or battery, the other may be brought into communication with the inner coatings by means of a common discharging rod (Fig. 36). For some experiments it is more convenient to fix the substance on which the experiment is to be made in a mahogany frame F, consisting of two small boards which can be pressed together by screws, and which may be substituted for the table. In either of these ways the charge can be directed through any part of the substance with the greatest accuracy.

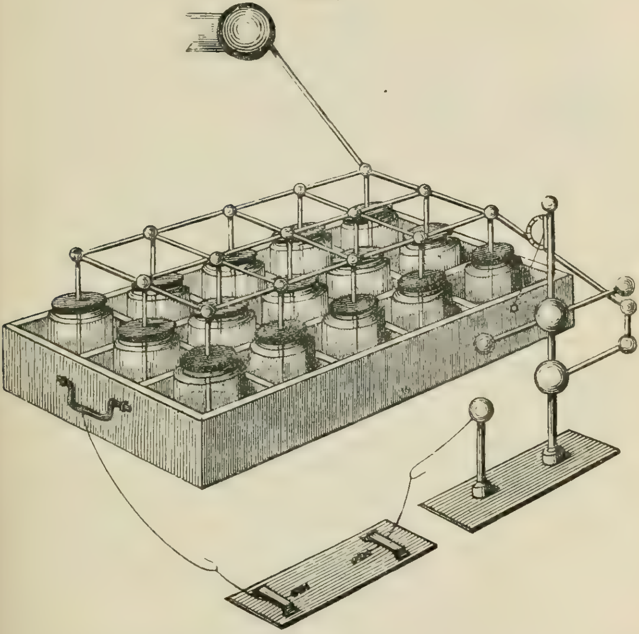
Fig. 42.



(26) **The Leyden Battery.**—Where several jars are electrically united together the arrangement is called an *Electrical Battery*. Fig. 43 represents such an apparatus. It consists of fifteen jars, the inside coatings of all of which are metallically connected by brass rods, and the bottom of the box in which they stand being lined with tin foil, secures a continuous conducting surface for the exterior coatings. The battery is shown with a *Cuthbertson's Balance Electrometer*, and an apparatus for deflagrating metallic wires attached. It is charged in the same manner as a simple jar, by connecting the metallic rods in communication with the inside coatings with the prime conductor, as shown in the figure, the metallic lining of the box being in good communication

either with the negative conductor or with a good discharging train. Harris prefers to dispose the jars round a common centre, that centre being in communication with the prime conductor, and the other jars being in connection with it and with each other.

Fig. 43.



By thus multiplying the number of jars, we have it in our power to accumulate electricity to an extent limited only by the charging power employed. A prodigious apparatus was constructed towards the end of the last century by Cuthbertson for the Tylerian Society at Haerlem. It consisted of 100 jars, each of $5\frac{1}{2}$ square feet, so that the total amount of coated surface was 550 square feet. This battery, when charged with a very powerful machine, produced the most astonishing effects. It magnetised large steel bars, rent in pieces blocks of boxwood 4 inches square, melted into red-hot globules iron wires 25 feet long and $\frac{1}{140}$th of an inch in diameter, and dissipated in a cloud of blue smoke tin wires 8 inches long and $\frac{1}{18}$th of an inch in diameter.

The management of large electrical batteries requires considerable caution, as the discharge of a far smaller extent of coated surface than that just described through the body of the operator would be attended with disagreeable consequences; by employing the ingenious balance electrometer of Coulomb all danger is avoided.

(27) **Return Charge.**—After a jar or battery has been charged for some time and then discharged, it is found that it will spontaneously recover its charge to a certain extent. This assumption for a time of a charged state of the glass, and which gives rise to the phenomenon called return charge, is referred by Faraday to the actual penetration of the charge to some distance within the glass. Under the coercive influence of the forces concerned, a portion of the positive and negative forces penetrates and takes up a position within the dielectric, and being thus nearer to each other, their mutual induction will be greater and their external induction less than when separated by the whole thickness of the dielectric. On the discharge of the jar or battery taking place, the forces by which the electric charge was driven into the glass are removed, and the penetrated electricity slowly returns to the exterior coatings. The experimenter should be on his guard against the effects of this residual charge when operating with large batteries. Faraday noticed the phenomenon with *shell lac*; he observed it also with *sulphur* and *spermaceti*.

(28) **Spontaneous Explosion.**—The tendency of jars to spontaneous explosion when very clean and dry may be diminished by pasting a slip of writing-paper, about one inch broad, on the inner surface of the jar, so as to cover the uncoated interval to the height of half an inch above the upper edge of the inner coating. The action consists, according to Singer (*Elements of Electricity*, p. 135), in a gradual diminution of the intensity of the charge at that part from which it has the greatest tendency to explode, by an extension of the charged surface through the medium of an imperfect conductor. It was remarked by Cuthbertson in 1792 that jars the inside of which were a little damp would take a higher charge than they could do when quite dry. He found—

That a jar containing 168 square inches of coating, made very dry and arranged with his balance electrometer, and eight inches of watch pendulum wire included in the circuit, discharged spontaneously without affecting the separation of the balls when the slider was set at *thirty degrees*; but that when the inside of the jar was moistened by breathing into it no spontaneous explosion occurred, but the discharge took place through the electrometer fusing the wire into balls.

(29) **Experimental Illustrations of the Effects of Accumulated Electricity.**—The phenomena attending the charge

and discharge of coated glass are illustrated in the following experiments :—

1. *Opposite electrical states of the inner and outer coatings.*—Let a bent metallic wire *b*, terminating in a knob *c*, be attached to the exterior of a jar *a*, so that *c* and the ball *d* of the jar are in the same line. Let a small pith-ball be suspended by a silk thread exactly midway between the two balls. The jar being charged, the pith-ball will be immediately attracted by *d*, and then repelled to *c*; again attracted by *d*, and again repelled to *c*; and this will continue for a considerable time. When the motion has ceased, let the discharging rod be applied to the jar in the manner shown in Fig. 36. No spark or snap will result, proving that the jar has been silently discharged by the pith-ball; the motion of which, between *d* and *c*, showing also the opposite electrical states of the two balls, and consequently of the outer and inner coatings. The same kind of experiment may be made with the *electric bells* (Fig. 45). Place the charged jar on an insulating stand, and make a communication between its interior and the insulated frame of the bells. The two exterior bells are suspended by metallic chains, but the central bell with the two clappers hang from silken threads, the middle bell is connected with the earth by a chain; the moment the outside of the jar is connected with the earth the clappers will be set in motion: then by touching the exterior coating from time to time with the finger, the bells may be made to ring at pleasure.

Fig. 44.

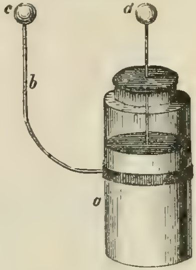


Fig. 45.

2. *Lichtenberg's Figures.*—Make the resinous cake of an electrophorus (Fig. 12, p. 13) dry and warm, draw lines on it with the knob of a positively charged jar, and sift over these places a mixture of *sulphur* and *red lead*; on inclining the plate so as to allow the powder to fall off, every line marked by the knob of the jar will be observed to be covered with the sulphur, while the red lead will be dispersed. If the same experiment be made with a jar charged with the *negative* conductor, the sulphur will be dispersed, and the red lead will be collected. The reason is this: the sulphur and red lead, by the friction to which they have been subjected, are brought into opposite electrical states; the sulphur is rendered negative and the red lead positive, so that when the mixture is made to fall on surfaces possessing one or the other electricity in a free state, the sulphur will be collected on the positive, and the red lead on the negative portions of the plate, according to the well-known laws of attraction and repulsion.

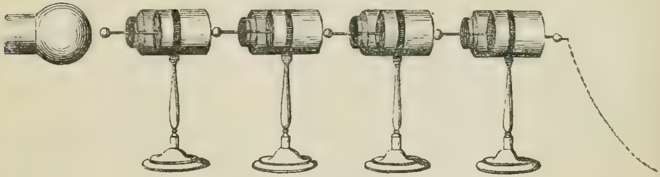
This beautiful experiment may be varied by tracing various lines on a smooth plate of glass with the knob of a jar, charged first positively and

then negatively : on gently dusting the surface with a mixture of sulphur and red lead, a series of red and yellow outlines, known as Lichtenberg's figures, will be formed.

3. *Free charge.*—Provide a jar, the exterior coating of which is movable. Charge this jar in the usual manner, and then place it on an insulating stand ; touch the knob from time to time with a conducting body, the whole charge will thus ultimately be removed, and the glass will be brought to its natural state. Now charge the jar again, remove the outer coating, and replace it on the insulating stand ; in this state it will retain its charge for an indefinite period. The reason of this is, that the wire by which the charge is communicated to the interior coating being left attached to it, induction does not take place solely through the glass to the opposite coating, but is partly directed through the air to surrounding conductors. This portion is usually called 'free charge,' and on removing this by touching the knob with a conducting body, a corresponding portion of *free charge* of the opposite kind makes its appearance on the outside coating, owing to the induction, which is now at liberty to direct itself from that part to surrounding objects. But when the exterior coating is removed, the induction is determined entirely *through the glass*, and the charge on one side is sustained by an exactly equal quantity of the contrary electricity on the other ; all interference with the surrounding objects is thus cut off.

4. *Jars charged by cascade.*—Let a series of jars be arranged on insulating stands, as shown in Fig. 46, taking care to establish a good electrical con-

Fig. 46.



nection between the outside of the last jar and the earth ; for every spark that passes between the prime conductor and the ball of the first jar, sparks will pass between the outside of that jar and the ball of the second, between the outside of the second and the ball of the third, and so on : after a time all the jars will be charged, and each may be discharged singly, or the whole may be so connected as to produce *one* discharge, the force of which shall be equal to the sum of all the separate ones. For this purpose the jars are placed upright on one common conducting basis, and their inner coatings metallically connected together, the whole series may then be discharged precisely as a single jar.

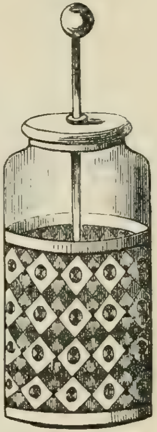
Mr. Baggs has described a method of charging and placing the jars by which a disruptive spark of unusual length and brilliancy is produced. The jars are charged separately and to the same degree of intensity, then placed quickly in series of positive and negative surfaces very near to each other but not touching.

The method of charging a series of jars '*by cascade*' was invented by

Franklin, to illustrate his theory, that when a jar is charged, it contains really no more electricity than it did before, and that during the act of charging the same quantity of '*fire*' was thrown out of one side of the glass as was thrown on the other side from the conductor or the machine.

5 *The luminous or diamond-spotted jar.*—Let a large jar be coated in the manner shown in Fig. 47. The tin foil is cut in pieces, each about one inch square, and perforated with a hole about four-tenths of an inch in diameter. These pieces are pasted on both sides of the glass, so that the diagonals of the squares are arranged horizontally and vertically, their points being separated about $\frac{1}{12}$ of an inch outside, and in the inside the points nearly touching one another at the centres of the circular holes of the outer squares. During the charging of the jar the sparks are seen jumping from one metallic surface to the other; and when the jar is discharged, every part of the jar within the boundaries of the metallic spangles becomes momentarily illuminated, presenting in a darkened room a brilliant appearance, and furnishing a beautiful illustration of the theory of the Leyden phial.

Fig. 47.



6. *The charge resides on the opposite sides of the glass.*— To demonstrate this let a jar be provided with movable coatings, the wire communicating with the interior coating passing through a glass tube, by which it may be removed from the jar without touching the metal; or let it be curved in the upper part so that it may be removed by a hooked wire attached to a glass handle. Let the jar be charged in the usual manner, then let the inside coating be carefully withdrawn, and having set it aside let the jar be inverted upon some badly conducting body, such as the table cloth, and let the exterior coating be removed; then on applying the discharging rod to the two coatings, or taking them in the hands, no spark or shock will be produced, proving them to be free from electrical charge. Let them now be replaced in the jar, and complete the circuit with the discharging rod, discharge accompanied with the usual phenomena will result, proving that the charge of the phial is dependent on the dielectric glass, and that the use of the coatings is to furnish a ready means of communication between the charged particles.

7. *Powerful mechanical, heating, and luminous effects.*—(1) Place a thick card or some leaves of a book against the outer coating of a charged Leyden phial, or between the knobs of the universal discharger, pass the explosion, the discharge will pass through the paper or card, perforating it and producing a burr or protrusion in both directions, as though the force producing it had acted from the centre of the card outwards; or insert two wires into a piece of wood about half an inch long and a quarter of an inch thick, so that the ends of the wires within the wood may be about $\frac{1}{8}$ of an inch apart, pass a strong charge through the wires, and the wood will split with

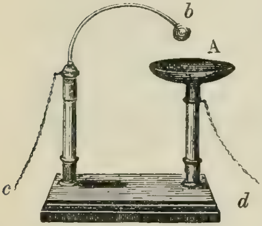
violence; or, hang two curved wires, provided with a knob at each end, in a wine glass nearly full of water, as shown in Fig. 48, so that the knobs shall be about half an inch asunder, connect *a* with the outer coating of a large Leyden phial, and *b* with the inner coating by means of the discharging rod, when the explosion takes place the glass will be broken with violence; or, place a piece of stout glass between the boards of the press of the universal discharger, and send a powerful charge through it, the glass will not only be broken, but portions of it even reduced to powder.

Fig. 48.

(2) Tie some tow loosely round one of the knobs of the discharging rod, and dip it in powdered resin, place the naked knob in contact with the outside of a charged phial, and bring the other quickly in contact with the ball connected with the inner coating, discharge will take place and the resin will burst into a flame.

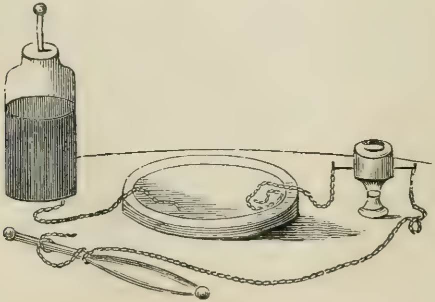
(3) Place some gunpowder in the insulated wooden cup A, Fig. 49, and bring immediately over it the brass ball *b*, which moves on a ball and socket joint on the top of a glass pillar, connect the chains *c d* with the outer and inner surfaces of a charged Leyden phial, discharge takes place and the gunpowder is inflamed.

Fig. 49.



Gunpowder cannot be inflamed by a discharge through *good* conductors, in consequence of the enormous velocity with which electricity travels (280,000 miles in a second, according to the experiments of Wheatstone); this may be proved by placing some powder on the ivory slip of the universal discharger, Fig. 42, and causing an explosion from a charged Leyden phial to pass through it; the powder will be scattered in all directions, but *not*

Fig. 50



ignited. If now some gunpowder be placed in a small ivory mortar, as shown in Fig. 50, and the circuit interrupted by ten or twelve inches of water in a porcelain basin, it will be fired on discharging the jar through it, because of the retarding influence of the imperfectly conducting water.

(4) Arrange five or six eggs in a straight line, and in contact with each other, they will become luminous on passing a small charge through them. The following substances are rendered phosphorescent for a time by the transmission of the electric spark through them, acquiring various colours: viz. chalk, orange; rock-crystal, first red then white; sulphate of barium, bright green; calcined oyster shells, the prismatic colours; loaf sugar, green.

8. *Deflagration of metals.*—Let a slip of tin foil or of gold leaf be placed between two pieces of paper, allowing the ends to project, and let the whole be firmly pressed together between the boards of the press of the universal discharger, transmit the shock of a large highly charged jar through it, the metals will be burnt; if gold leaf be employed, the paper will be found to be stained of a purplish blue colour.

For deflagrating metallic wires the battery is required; the arrangement is shown in Fig. 43. The wires are stretched above sheets of white paper, and powerful discharges sent through them. The results are exceedingly beautiful—the wires disappear with a brilliant flash, leaving different-coloured impressions on the paper, e.g.—

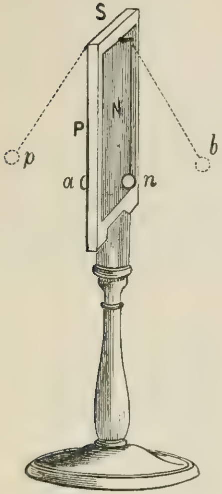
	Diameter of wire.	Colour produced.
Gold wire . .	$\frac{1}{180}$ of an inch .	. Purple and brown.
Silver . . .	$\frac{1}{160}$ " .	. Grey, brown, and green.
Platinum . .	$\frac{1}{180}$ " .	. Grey and light brown.
Copper . .	$\frac{1}{160}$ " .	. Green, yellow, and brown.
Iron . . .	$\frac{1}{180}$ " .	. Light brown.
Tin . . .	$\frac{1}{180}$ " .	. Yellow and grey.
Zinc . . .	$\frac{1}{180}$ " .	. Dark brown.
Lead . . .	$\frac{1}{180}$ " .	. Brown and blue grey.
Brass . . .	$\frac{1}{180}$ " .	. Purple and brown.

9. *Equality of the Electricity on the inner and outer surfaces.*—Let a plate of coated glass, S, Fig. 51, be placed vertically on a stand, and let two pith-ball electroscopes, *p n*, be attached to the coatings. Bring the coating P into contact with the prime conductor, the coating N being in good conducting communication with the ground. As the charging proceeds, the ball *p* will be repelled by the free electricity of P, while the ball *n* retains its original position. On allowing the apparatus to remain undisturbed for some time, the free electricity of P will be gradually dissipated, and the ball *p* will drop into its original position. Now charge the plate again, and immediately cut off the communication between N and the ground. The ball *p* will slowly descend towards P as before, but at the same time *n* will begin to rise, and by the time *p* has reached the position *a*, *n* will have risen to *b*, the angle between the balls being about the same as at first. Both balls will then slowly sink till the charge is lost by dissipation. If during the descent of the balls we touch N, the ball *n* will suddenly sink, and *p* will as suddenly rise by an equal amount on removing the finger from N; *p* will fall and *n* will rise to nearly their former places, and the slow descent of both will recommence. The same thing will happen if we touch P; *p* will fall down close

to the plate and *n* will rise, and so on: and these alternate touchings of the coatings may be repeated a great many times before the plate is discharged.

In order to understand this instructive experiment, it must be remembered that as long as N is in communication with the ground it cannot retain any free electricity, and therefore, under these circumstances, the ball *n* can never be repelled; but as the free electricity on P is dissipated, a corresponding portion of the opposite electricity must be liberated from N and escape to the earth; and this action must go on till the entire charge is lost. But when *both* surfaces are *insulated*, or the free electricity of P is dissipated, a corresponding quantity of the opposite electricity is liberated as before from N; but as it cannot now escape to the earth, it becomes free electricity, and repels the electroscope *n*. But this free electricity becomes gradually dissipated, and thus the entire charge is after a time lost.

Fig. 51.

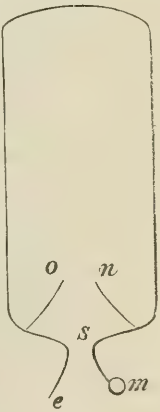


The same general principles may be illustrated with a Leyden jar thus: let the jar (the outer coating of which is a little higher than the inner) be charged, and its ball and rod be immediately removed by a silk thread; now apply a carrier ball to either the inside or the outside coating; no signs of electricity will be obtained, the two forces being entirely engaged to each by induction through the glass. Now insulate the jar, and restore the ball and rod. Under these circumstances induction will take place through the air towards external objects, the tension of the polarised glass will fall, and the parts projecting above the jar will give electrical indications and charge the carrier; at the same time the *outside* coating will be found in the opposite electrical state. Again, place a cylinder of wire gauze on a plate of shell lac, and over it, but *not* resting on the lac, another similar but larger cylinder; these cylinders correspond with the coatings of a Leyden jar, the glass of which is represented by the intervening dielectric *air*; let a small charge of electricity be conveyed from the prime conductor of an electrical machine to the inner cylinder, by means

of a brass ball suspended by a silk thread. On now touching the *inner* coating of the *inner* cylinder with a disc of gilt paper insulated by a stick of lac, and then examining its condition by the electroscope, it will be found to be neutral; but on passing the proof plane between the two cylinders and touching the *outer* coating of the *inner* one, it brings away a charge of positive electricity. In like manner on touching the *outer* side of the *outer* cylinder no electricity is obtained, but from the *inner* side a *negative* charge is transferred to the disc, which is rendered sensible by bringing the latter into contact with the electroscope.

10. *Resistance to the transmission of Electricity even by the best Conductors; Lateral Induction.*—Let a long copper wire, having at the end *m* a metallic ball, be suspended in the air; let its end *e* be connected with the earth, and let the part near *m* and *e* be brought within half an inch of each other at *s*; now let a Leyden phial be discharged through the wire by connecting its outside with *e* and its inside with *m*, a bright spark will appear at *s*, because with a great length of wire the resistance is accumulated until it becomes as great, or even greater, than that of the air for electricity of such high intensity. Let a variation be introduced into the experiment; and the interval at *s* being so adjusted that the sparks freely pass there on discharging the jar through the wire, let the wires *n* and *o* be connected with the inside and outside coatings of a second insulated jar. Under these circumstances no spark will appear at *s*, because, in consequence of the *lateral induction* momentarily allowed by the interposition of the jar between the side wires, the intensity is lowered, and the quantity of electricity, though always the same, is not sufficient to strike across the interval at *s*, but is finally occupied altogether in the wire, which, in a little longer time than before, effects the whole discharge.

Fig. 52.



It is to this '*lateral induction*' that certain remarkable phenomena observed some years ago by Mr. Latimer Clark, at the works of the Electric Telegraph Company, are, according to Faraday, to be ascribed.

When contact was made between the free end of an insulated intensity voltaic battery and one end of 100 miles of a submerged telegraphic cable covered with gutta-percha, the outer end of the battery being in communication with the earth, it was found that after the contact had been broken for two or three minutes a smart shock could be received by a person touching the wire; a fuze could be fired, and the galvanometer powerfully affected. The submerged wire became in fact an immense Leyden battery, and was charged *statically* by the electricity of the voltaic battery, and,

acting by induction through the gutta-percha, produced the opposite state on the surface of the water touching the gutta-percha, and forming the outer coating. The intensity of the static charge acquired is only equal to the intensity at the pole of the battery, but the quantity, because of the immense extent of the coated surface, is enormous, hence the striking character of the results. The reason why no such effects are obtained in a wire suspended in the air is simply because there is in this case no *outer* coating corresponding to the water, and as therefore there is no induction, so the inner wire cannot become charged. But precisely similar phenomena are exhibited by subterranean wires covered with gutta-percha and enclosed in metallic tubes.

(30) **Free Charge and dissimulated Electricity.**—The charge upon an insulated conductor in the middle of a room is in the same relation to the walls of that room as the charge upon the inner coating of a Leyden jar is to the outer coating of the same jar: one is not more *free* or *dissimulated* than the other; and when we sometimes make electricity appear where it was not evident before, as upon the outside of a charged jar, when after insulating it we touch the inner coating, it is only because we divert more or less of the inductive force from one direction into another, for not the slightest change is in such circumstances impressed upon the character or action of the force, and the terms '*free charge*' and '*dissimulated electricity*' convey erroneous notions if they are meant to imply any difference as to the mode or kind of action. The difference between electrical accumulation on coated glass and that on simple conductors is only in degree of effect; the laws incidental to the electrified substance remain the same.—(*Faraday.*)

(31) **Lateral Discharge.**—If a charged jar be placed on an insulating stand and discharged in the usual manner by a discharging rod, at the moment of discharge a small spark will pass between the outer coating and a body in communication with the earth. When a jar is discharged by a curved wire held in the hand, without an insulating handle, a slight shock is frequently felt in the hand that grasps the wire; and if a chain be laid on the table with one end touching the outside of a charged jar, it will become illuminated on the discharge of the jar, although it forms no part of the circuit.

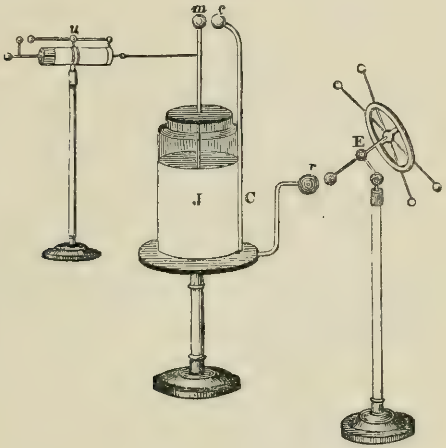
These effects are due to what is termed the 'lateral discharge,' and are occasioned by a small excess of *free* electricity, which distributes itself over a discharging surface, when a charged system is discharged or neutralised. When a jar is charged, the accumulated electricity is never exactly balanced between the opposed coatings, so that there will always be an excess of positive or

negative electricity *over* the neutralising quantities themselves disposed on the coatings of the jar.

The following experiments will convey a good deal of information respecting the nature of the so-called *lateral discharge* (*Harris*):—

1. Let the jar J, Fig. 53, be charged *positively*, removed from the machine, and insulated; under this condition discharge it. When discharged, let the electrical state of the knob *m*, discharging conductor *e* C, and outer coating J

Fig. 53.



be examined; they will all be found in the same electrical state, which state will be that exhibited by the outer coating and knob while charging, and the small residuary charge will be *plus*.

2. Let the jar be charged as before; but before discharging it, withdraw the free electricity from the knob. The electrical state of the coating and appendages will now be changed, and the small residuary charge will be *minus*.

3. Immediately *after* the discharge apply a metallic body to the coating J; a residuary spark will be thrown off, and the jar will be found again slightly charged, showing the spark to be merely a residuary accumulation.

4. Charge a jar, exposing about two square feet of coating, with a given quantity of electricity, measured by the unit jar *u*; let a conducting rod, terminating in a ball *r*, project from the outer coating, and place near it the electroscope E. Discharge the jar through the rod *e* C as before, and observe the amount of divergence of the electroscope. Double the capacity of the jar, and again accumulate and discharge the same quantity. The divergence of the electroscope will be very considerably decreased: add a second and a third jar to the former, and the effect will at last be scarcely perceptible;

connect the jar with the ground, and with a given quantity the spark will vanish altogether.

5. Accumulate a given quantity as before, and observe the effect of the residuary charge on the electroscope. Let a double, treble, &c., quantity be accumulated and discharged from a double, treble, &c., extent of surface—that is, for a double quantity employ two similar jars, and so on—the effect will remain the same.

These two last experiments prove that the spark is of different degrees of force when the electricity is discharged from a greater or less extent of surface, whilst double, treble, &c., quantities, when discharged from double, treble, &c., surfaces, give the same spark. The spark, therefore, is not caused by any lateral explosion from the discharging rod, but depends entirely on the jar.

Lateral sparks may be drawn from a wire in good communication with the earth whilst it is receiving dense sparks from an electric machine in vigorous action. These sparks result from the inductive action of the electricity accumulated on the conductor upon the vicinal conducting substances, which, completing the terminal surface of a charged system, determines the charging of the stratum of air between them, and sparks will consequently strike off from the wire to these free conducting bodies as long as sparks continue to pass between the two conductors. If the wire from which these lateral explosions proceed be connected directly with the machine, the phenomena disappear, because the accumulation on the conductor is prevented from reaching any great intensity. It is necessary, therefore, to employ disruptive discharges between opposed conductors, and the larger the surface of the charged conductor the greater is the effect produced.

(32) **Laws of Electrical Accumulation.**—These have been minutely studied by Harris (*Trans. Plymouth Institution* and *Trans. Royal Society*, 1834, 1836, 1839), with the aid of two valuable electrical instruments which he invented, viz. the *electro-thermometer* and the *unit jar*.

The Electro-Thermometer.—This is shown in Fig. 54. It consists of an air thermometer, through the bulb of which there is stretched air-tight a fine platinum wire; the bulb is screwed also air-tight on a small open vessel containing a coloured liquid, and soldered to the extremity of a long bent glass tube, to which is adapted a graduated scale; the fluid is adjusted to the zero of the scale by a small screw valve at the top of the bulb. When an electrical accumulation is discharged through the platinum wire it becomes heated more or less, expanding the air and forcing the coloured fluid up the vertical tube, the height to which it ascends being measured on the scale.

The height to which the liquid rises is as *the square of the quantity of electricity discharged.*

The Unit Jar.—This is shown in Fig. 55. It consists of a small jar, K, exposing about six inches of a coated surface, inverted on a brass rod fixed

to the conductor of the machine, or otherwise sustained on a separate insulation; and the jar or battery to be charged is connected with its outer surface by means of a brass rod and ball, *b*. In this arrangement electricity is continually supplied to the jar, and the amount of accumulation is accurately

Fig. 54.

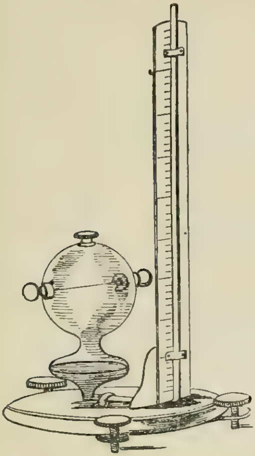
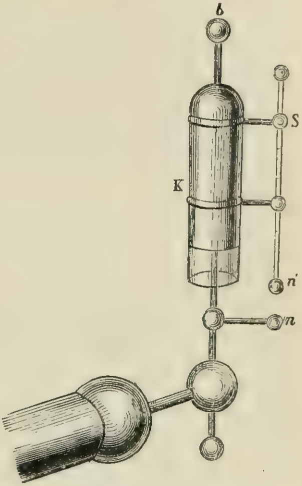


Fig. 55.



measured by the number of charges which the unit jar has received; the charges being determinable by means of the discharging balls *n n'*. By increasing or diminishing the distance between the discharging balls, the value of the unit may be rendered as great or as small as we please. Hence if the balls be securely fixed, and the distance between their points of discharge accurately measured by means of a micrometer screw and index at *s*, comparative quantities may be always estimated and restored from time to time with great accuracy.

1. Equal quantities of electricity are given off at each revolution of the plate of an electrical machine to an *uncharged* surface, or to a surface *charged* to any degree of saturation.

2. A coated surface receives equal quantities of electricity in equal times; and the number of revolutions of the plate is a fair measure of the relative quantities of electricity, all other things remaining the same.

A jar containing about five square feet of coated surface was charged with four turns of the machine, and then discharged through the thermo-electrometer; the fluid rose *nine* degrees. The jar was now placed on an insulating stand, and its external coating connected by a wire with the internal coating of a second and precisely similar jar, uninsulated and provided with a Lane's discharging electrometer (Fig. 40), the thermo-electrometer being likewise

included in the circuit. After four turns of the machine the second jar was discharged, and the fluid rose as before, *nine* degrees. The small residuum in the second jar being removed (the first jar retaining its charge), the machine was again put in motion, and after four turns the discharge of the second jar again took place, and the fluid again rose *nine* degrees.

When the second jar was much smaller than the first, the explosion took place about each turn of the plate, till the large insulated jar was fully charged; and as in both cases the second jar was charged from the outer coating of the first, its explosions may be taken as fair measures of the relative quantities of electricity communicated by the machine; and as these explosions correspond to equal numbers of revolutions, it follows that the accumulations in the insulated jar must have proceeded by equal increments, and consequently that equal quantities of electricity were thrown on at each time.

3. The free action of an electrical accumulation is estimated by the interval it can break through, and is directly proportional to the quantity of electricity.

Two similar jars, each containing five square feet of surface, being connected together, and with a Lane's discharging electrometer, the balls being set at $\frac{1}{10}$ of an inch apart, the discharge took place at the ends of *two and a half* turns of the machine; the interval being doubled, the charge passed at the end of *five* turns; the interval being *trebled*, at *seven* turns; when the interval between the balls amounted to $\frac{4}{10}$ of an inch, it required *ten* turns of the machine to produce a discharge.

4. The free action is inversely proportional to the surface.

One of the jars in the previous experiment being removed, and the balls set at $\frac{4}{10}$ of an inch, the discharge took place with *five* turns of the machine; the second jar being returned to its place, and the balls set at $\frac{2}{10}$ of an inch, the discharge again took place with *five* turns; and on adding two more similar jars and setting the balls at $\frac{1}{10}$ of an inch, or one quarter the first distance, the discharge still took place with *five* turns.

5. When the electricity and the surface are increased in the same ratio, the discharging interval remains the same; but if, as the electricity is increased, the surface is diminished, the discharging interval is directly as the square of the quantity of electricity.

The balls of the electrometer being set at $\frac{2}{10}$ of an inch, the discharge of a single jar took place with $2\frac{1}{2}$ turns; a second similar jar being added, the balls remaining as before, the discharge took place at five turns; a third jar being added with *seven* turns: two similar jars being used, the interval remaining the same, the discharge took place at *five* turns; but when one jar—that is, half the surface—was removed, and the balls set at $\frac{8}{10}$ of an inch, the discharge occurred at *ten* turns.

If we represent the quantity of electricity by Q, the interval by I, and the surface by S, we get the following equation:—

$$I = \frac{Q}{S}; \; Q = S I.$$

6. The resistance of air to discharge is as the square of the density directly.

The balls of the discharging electrometer being set at a certain distance apart in the receiver of an air pump, and the density of the air being diminished to *one-half*, discharge occurs with *one-half* of the quantity of electricity accumulated—that is, with *one-fourth* of the intensity of free action—and the distance through which a given accumulation can discharge is in the inverse simple ratio of the density of the air: in air of one-half the density the discharge occurs at twice the distance.

(33) **Harris's later Investigations.**—Sir Wm. Snow Harris has (June 8, 1864) communicated to the Royal Society the results of some further inquiries concerning the laws and operations of electrical force. The quantity of electricity which any plane rectangular surface can receive under a given intensity, he finds to depend not only on the surface, but also on its *linear* boundary extension. Thus the linear boundary of 100 square inches of surface under a rectangle 37·5 inches long by 2·66 inches wide is about 80 inches, whilst the linear boundary of the same 100 square inches of surface under a plate 10 inches square is only 40 inches. Hence the charge of the rectangle is much greater than that of the square, although the surfaces are nearly equal.

The amount of electrical charge depends upon surface and linear extension conjointly. There exists in every plane surface what may be termed an *electrical boundary* having an important relation to the grouping or disposition of the electrical particles in regard to each other and to surrounding matter. This boundary in circles or globes is represented by their circumferences. In plane rectangular surfaces it is their linear extension or *perimeter*. If this *boundary* be constant, their electrical charge varies *with the square root of the surface*. If the *surface* be constant, the charge varies with *the square root of the boundary*. If the surface and boundary both vary, the charge varies with the *square root of the surface multiplied into the square root of the boundary*.

Thus calling C the charge, S the surface, B the boundary, and μ some arbitrary constant depending on the electrical unit of charge, we have

$$C=\mu\sqrt{S \, . \, B}$$

which will be found, with some exceptions, a general law of electrical charge.

It follows from this formula, that if when we double the surface we also double the boundary, the charge will also be double. In this case the charge may be said to vary with the surface, since it varies with the square root of the surface multiplied into the square root of the boundary. If, therefore, the surface and boundary both increase together, the charge will vary with the square of either

quantity. The quantity of electricity, therefore, which the surfaces can sustain under these conditions will be as the surface.

If l and b represent respectively the length and breadth of a plane rectangular surface, then the charge of such a surface is expressed by

$$\mu \sqrt{2\,l\,b\,(l+b)}$$

which is found to agree perfectly with experiment.

It is necessary, however, to bear in mind the difference between *electrical charge* and *electrical intensity.* By the former Harris understands the quantity which can be sustained upon a given surface under a given electrometer indication; by the latter the '*electrometer indication*' answering to a given quantity upon a given surface. By the term *quantity of electricity,* he understands the actual amount of the unknown agency constituting electrical force as represented by some arbitrary quantitative electrical measure.

The electrical intensity of plane rectangular surfaces Harris found to vary in an inverse ratio of the boundary multiplied into the surface. If the surface be constant the intensity is inversely as the boundary. If the boundary be constant the intensity is inversely as the surface. If both vary alike and together, the intensity is as the square of either quantity, so that if when the surface be doubled, the boundary be also doubled, the intensity will be inversely as the square of the surface. The intensity of a plane rectangular surface being given, we may always deduce therefrom its electrical charge under a given greater intensity, since we only require to determine the increased quantity requisite to bring the electrometer indications up to the given required intensity. This is readily deduced, the intensity being by a well-established law of electrical force as the *square of the quantity.*

These laws relating to charge, surface, intensity, &c., apply more especially to continuous surfaces taken as a *whole,* and not to surfaces divided into separate parts. If the result of an electrical accumulation upon a plane rectangular surface taken as a whole be examined, and the results of the same accumulation upon the same surface divided into two equal and similar portions distant from each other, it is found that if as the quantity is increased the surface and boundary be likewise increased the *intensity does not change.*

If three or more separated equal spheres be charged with three or more equal quantities of electricity, and be each placed in separate connection with the electrometer, the intensity of the *whole* is not greater than the intensity of *one* of the parts. Similarly, a battery of five equal and similar jars charged with a given quantity of electricity = 1, has the same intensity as a battery of ten equal and similar jars with a quantity = 2, so that the intensity of the ten jars taken together is no greater than the intensity of one of the jars taken singly.

In accumulating a double quantity upon a given surface divided into two equal and separate parts, the boundaries of each being the same, the intensity varies inversely as the square of the surface, hence two separate equal parts can receive, taken together under the same electrometer indication, *twice* the quantity which either can receive alone, in which case the charge varies with the surface.

Thus if a given quantity of electricity be disposed upon two equal and similar jars instead of upon one of the jars only, the intensity upon the two jars will be only *one-fourth* the intensity of one of them, since the intensity in this case varies with the square of the surface inversely, whilst the quantity upon the two jars under the same electrometer indication will be double the quantity upon one of them only; in which case the charge varies with the surface, the intensity being constant. If, therefore, as we increase the number of equal and similar jars we increase also the quantity, the intensity remains the same, and the charge will increase with the number of jars.

Taking a given surface, therefore, in equal and divided parts—as, for example, *four* equal and similar electrical jars—the intensity is found to vary with the square of the quantity *directly* (the number of jars remaining the same) and with the square of the surface *inversely* (the number of jars being increased or diminished); hence the charge will vary as the square of the quantity divided by the square of the surface, and we have, calling C the charge, Q the quantity, and S the surface,

$$C = \frac{Q^2}{S^2}$$

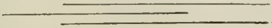
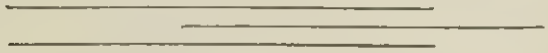
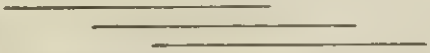
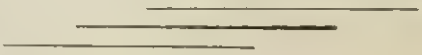
which formula fully represents the phenomenon of constant intensity attendant upon the charging of equal separated surfaces with quantities increasing as the surfaces, as in the case of charging an increasing number of equal electrical jars.

(34) **Velocity of Electricity.**—This is so great that the most rapid motion that can be produced by art appears to be actual rest when compared with it. A wheel revolving with a rapidity sufficient to render its spokes invisible, when illuminated by a flash of electricity is seen for an instant with all its spokes distinct, as if it were in a state of absolute repose; because, however rapid the rotation may be, the light has come and already ceased before the wheel has had time to turn through a sensible space. Insects on the wing, when electrically illuminated, appear fixed in the air; and a rapid succession of drops of water, appearing to the unaided eye a continuous stream, is seen under the electric light to be what it really is.

Let a circular piece of pasteboard be divided into three sections; let one be painted *blue*, another *yellow*, and a third *red*. Cause it to rotate rapidly; it will appear white, because a sunbeam consists of a mixture of these colours, and the rapidity of the motion causes the distinction of colours to be lost to the eye; but the instant the pasteboard is illuminated by the electric spark,

it seems to stand still, and each colour appears as distinct as if the disc were at rest.

By a beautiful application of this principle, Wheatstone contrived an apparatus by which he demonstrated that the light of the electric discharge does not last the *one-millionth part* of a second of time. His plan was to view the image of a spark reflected from a plane mirror, which, by means of a train of wheels, was kept in rapid rotation on a horizontal axis. The number of revolutions performed by the mirror was ascertained to be 800 in a second, during which time the image of a stationary point would describe 1,600 circles, because from the laws of reflection the image of an object in a revolving mirror has *twice the angular velocity* of the latter, and the elongation of the spark through half a degree would indicate that it exists $\frac{1}{1152000}$th part of a second. A jar was discharged through a copper wire half a mile in length, interrupted both in the middle and also at its two extremities, so as to give three distinct sparks. The deviation of half a degree between the two extreme sparks would indicate a velocity of 576,000 miles in a second. This estimated velocity is on the supposition that the electricity passes from one end of the wire to the other; if, however, according to the *two-fluid* theory, the two electricities travel simultaneously from the two ends of the wire, the two external sparks will keep their relative positions, the middle one alone being deflected, and the velocity measured will be only one-half that in the former case, viz. 288,000 miles in a second.

The following were the results actually obtained:—In all cases when the velocity of the mirror exceeded a certain limit the three sparks were elongated into three parallel lines, and the lengths became greater as the velocity of the mirror was increased. The greatest elongation observed was about 24°, indicating a duration of about the 24,000th part of a second. When the velocity was low the terminating points appeared to be exactly in the same vertical line, but when the velocity was considerable, and the mirror revolved towards the right, the lines assumed the appearance , when it revolved towards the left they appeared ; but in no case were they seen  or  as required by the hypothesis of a single fluid.

There are, however, great discrepancies in the different measurements which have been recorded of the velocity of electricity, thus:—

Walker (America) with telegraph iron wire makes it	18,780	miles per second.
O'Mitchell (America) „ „	28,524	„ „

Fizeau and Gonnelle, copper wire, make it . . .	112,680 miles per second
" " iron wire " . . .	62,600 " "
[1] Astronomers of Greenwich and Brussels, copper, London and Brussels telegraph, make it	2,700 " "
Astronomers of Greenwich and Edinburgh, copper, London and Edinburgh telegraph, make it	7,600 " "

But in regard to the long circuits included in the above experiments, the conducting power of the wires cannot be understood, while no reference is made to their *lateral static induction* (p. 53), or to the conditions of intensity and quantity which then come into play, especially in the case of short or intermitting currents, for then static and dynamic are constantly passing into each other.—(*Faraday.*)

The rate at which signals can be transmitted through overhead wires is very much greater than upon submarine or underground lines, because the retardation is less.

Both aërial wires and cables are, however, subject to precisely the same laws, differing only in degree as regards retardation, and the same general formulæ, therefore, apply to both. Attempts have been made, at different times, to determine the transit velocity of the electric wave in line wires; and results have been arrived at which, although appearing to be very various and inconsistent as they are generally stated, are nevertheless, in most instances, reducible to concordant expressions. Where this is not the case, the difficulty lies in the absence of any information to guide us to a conclusion as to the conditions of induction and resistance under which the experiments were made.

In No. 8 of *The Telegraphic Journal* Mr. Robert Sabine drew attention to the fact that on the arrival at the far end of a line of an electric wave, work has to be done before the wave can be recognised, and that the issuing wave requires time to gain strength enough to perform this work. There are different ways in which this work has to be performed, according to the different ways in which the wave is recognised. In Sir C. Wheatstone's celebrated experiment, in 1835,[2] with a revolving mirror, he found through a copper wire, 0·2 inch diameter, suspended in the vaults of King's College, that a spark took $\frac{1}{1150000}$ second to pass from one end to the middle ($\frac{1}{4}$ mile in length), which represents a velocity of 288,000 miles per second. In this case mechanical effect was performed by the arriving wave in springing over $\frac{1}{10}$th inch of air in the form of a spark. The work it had to do was to collect on the other side, through $\frac{1}{4}$ mile of wire, a sufficient induced charge, and

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[1] *Athenæum*, January 14, 1854. [2] *Phil. Trans.* 1835, p. 583.

when it had done this to push back the intervening air and to jump across. If in this experiment, from the given data, we may roughly estimate the resistance by the $\frac{1}{4}$ mile of wire to have been 0·4 ohms, and its electrostatic capacity at 0·0025 micro-farad, which is at the rate of about $\frac{1}{30}$ that of an average submarine cable, that which I have called the coefficient of retardation would be—

$$a = \frac{1}{1150000 \times 0·4 \times 0·0025} = 870000 \times 10^{-9} \text{ seconds,}$$

that is to say, that as a receiving instrument, a spark apparatus having a striking distance of 0·1 inch would be $\frac{870000}{414}$, or about 2,000 times less sensitive than a Morse electro-magnet; in other words, that the time required for the arriving wave to get strength enough to do its work would be 2,000 times as long, and transmission by such a method 2,000 times as slow, as by Morse.

In 1848 Walker used a Bain's instrument for determining the velocity of a current in the line from Boston to New York, a wire length of 220 miles, and found that the signal occupied a mean of 0·0029 seconds. Assuming the line resistance to have been (17 ohms per mile) 3,740 ohms, and the capacity (0·01 micro-farad per mile) 2·2 micro-farads, the coefficient of retardation would have been—

$$a = \frac{0·0024}{3740 \times 2·2} = 291 \times 10^{-9} \text{ seconds.}$$

But Walker's results do not appear to have been very regular; and considering the crudeness of the method of measuring this was not surprising.

On the (1858) Atlantic Cable the coefficient of retardation appeared to be 414×10^{-9} seconds. On a double suspended line wire between Cincinnati and Pittsburg, Professor Mitchell [1] found, in 1850, employing an astronomical clock and electro-magnet, that on 607 miles of iron wire a signal took 0·02128 second. Assuming the line resistance at 17 ohms per mile, and the capacity at 0·01 micro-farad per mile, we have, R = 6·07, F = 10319, and—

$$a = \frac{0·02128}{10319 \times 6·07} = 340 \times 10^{-9} \text{ seconds,}$$

which very nearly agrees with the coefficient deduced from Whitehouse's experiment on the Atlantic Cable.

So does also a long series of experiments made by Gould,[2] in 1850, on 1,045 miles of overhead wire with Morse apparatus. He found the mean time occupied to be 0·086 second. If the line

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[1] *Pogg. Ann.* lxxx., p. 161. [2] *American Journal*, 2nd series, xi.

resistance was $17 \times 1045 = 17{,}765$ ohms, and the capacity $0{\cdot}01 \times 1045 = 10{\cdot}45$ micro-farads, the coefficient of retardation will have been—

$$a = \frac{0{\cdot}086}{17765 \times 10{\cdot}45} = 377 \times 10^{-9} \text{ seconds.}$$

In the same year, Fizeau and Gounelle[1] invented a very beautiful method of measuring the velocities of waves, which was intended to overcome the difficulty of *inertia* by the instrument; but it does not appear to be free from this drawback. In this system a rapid succession of periodical currents are sent into one end of the cable and received at the other by two alternate contacts working synchronously with the battery contact, and which direct the electricity in opposite directions through the wires of a galvanometer. When the line has no retardation, half of each wave neutralises the effect of the other half, and the galvanometer needle remains undeflected; but when a line is in circuit, the arriving wave being held back will be divided into two unequal parts, and the galvanometer having more current on one side than on the other will be deflected. By regularly increasing the speed, a series of maxima and minima deflections are observed; and by noting the speed at two following maxima—that is, the increased speed which is required to put one wave more into the line—the time of a wave travelling from the sending end to the galvanometer may be easily reckoned. With this method it would, at first sight, seem that *inertia* must be eliminated; that this is not so, however, appears from Fizeau and Gounelle's results.

With this apparatus they found, for example, on a No. 8 B. W. G. iron wire between Paris and Amiens—195 miles long—an apparent velocity of 62,600 miles per second; or that a wave took 0·0031 second to pass through. If this wire had the average resistance and capacity, its resistance would have been about 3,315 ohms, and its capacity 1·95 micro-farads; therefore the coefficient of retardation—

$$a = \frac{0{\cdot}0031}{3315 \times 1{\cdot}95} = 480 \times 10^{-9} \text{ seconds.}$$

And in a second experiment, the line between Paris and Rouen was used, 179 miles of wire, two-thirds of which was copper, 0·1 inch diameter, the resistance of which was probably 7 ohms per mile, and one-third of a No. 8 iron wire. The total line resistance

[1] *Comptes Rendus*, vol. xxx., p. 437.

was, therefore, about 1,853 ohms, and the capacity 1·79 micro-farad. The velocity found was 112,680 miles per second, the wave taking 0·0016 second to pass. From this the coefficient of retardation would be—

$$a = \frac{0{\cdot}0016}{1853 \times 1{\cdot}79} = 482 \times 10^{-9} \text{ seconds.}$$

In their account of this experiment, Messrs. Fizeau and Gounelle draw particular attention to the greater velocity of the current through copper than in iron wire. The student will, however, see that for unit length and capacity the reduced velocity would be identically the same in both lines, the same apparatus being used. If the high coefficient found from these experiments is due to *inertia* of the galvanometer needle, that would seem to be a less sensitive receiving instrument than an electro-magnet relay; and this is to some extent borne out by Prof. Hughes's experiments.

Fizeau and Gounelle's method was greatly improved on by Guillemin and Bournouf,[1] in 1854. They employed also a galvanometer, but without the differential method. The cable ends were connected with two contact tongues, which vibrated synchronously between contact anvils. At one end between a + and a – battery; at the other end between earth and the galvanometer, which was also connected to earth.[2]

An experiment was made by them on the Foix and Toulouse lines, two wires, each of 41 leagues, making together 245 miles of wire. The wave took $\frac{1}{1100}$ second. And assuming the constants of resistance and capacity to be the same as before, the coefficient of retardation would be—

$$a = \frac{1}{1100 \times 4165 \times 2{\cdot}45} = 89 \times 10^{-9} \text{ seconds.}$$

There is evidently a marked improvement, but still a result only half as good as that given by the mirror galvanometer.

Now these are the results which are generally set down as exceedingly discordant, but between which, when rightly interpreted, we find a very remarkable connection. In the following Table I have put them together so that a comparison may be readily drawn between the speeds as generally stated and the deduced coefficients, which is of much more importance for the student to study:—

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[1] *Comptes Rendus*, xxxix., p. 330.

[2] They really employed rotatory contacts; but this is the form given subsequently to the apparatus.

System	Observer	Line	Length	Speed in miles per second	Coefficient 10^9 times a
Mirror	Gould . .	Cable	1896 k.	8,300	47
Galvanometer .	Guillemin .	Wire	245 m.	111,700	89
Hughes's . . .	Clark. . .	Cable	462 k.	2,870	105
Bain	Walker . .	Wire	220 m.	19,500	291
Electro-magnet .	Mitchell .	Ditto	607 m.	28,524	340
Ditto. . . .	Gould . .	Ditto	1045 m.	15,890	377
Ditto. . . .	Whitehouse	Cable	1020 k.	816	414
Galvanometer .	Fizeau . .	Wire	195 m.	62,600	480
Ditto. . . .	Ditto . .	Ditto	179 m.	112,680	482
Spark 0·1″. . .	Wheatstone	Ditto	½ m.	288,000	870,000

At this date it is, of course, impossible to return to these experiments with any certainty as to the electrical constants of the materials employed. I have, therefore, assumed general average values; and the student will see that even with these how nearly the results accord with each other. Take as an example the experiments made with electro-magnets by different observers on different lines, with different apparatus, and under quite different conditions.

But one thing is certain, viz. that, whatever system is used, the time required for a wave to get strength enough to overcome the *inertia* of the apparatus is very great in proportion to the time actually occupied between the making of contact at one end of a wire, and the first instant of its arrival at the other end.

In future experiments, with improved apparatus and a better knowledge of how to interpret his results, it is open to the student to add valuable information to this branch of the science of electricity.—*Sabine.*

(35) **Physiological Effects.**—The sensation experienced when the body is made part of an electrical circuit through which a Leyden phial is discharged is too universally known to need description.

A small charge determined down the spine generally causes a person to fall to the ground; the discharge of a powerful battery in the same direction would probably prove fatal.

Animals the most tenacious of life are destroyed by energetic shocks passed through them. Van Marum found that eels are instantly killed when moderate shocks are sent through their bodies. It was first shown by Dr. Watson, soon after the discovery of the Leyden phial, that the shock may be transmitted through the bodies of several men touching each other. For this purpose, all must join hands, the first touching the outside of the phial, and

the last the knob; those in the centre will receive a less violent shock than those near the two extremities of the chain, a phenomenon which favours the hypothesis of two fluids. Dr. Watson in 1747 conveyed the electric shock across the Thames at Westminster bridge, and a few days after he caused it to make a circuit of two miles at the New River at Stoke Newington. The Abbé Nollet communicated a shock to an entire regiment of 1,300 men; and at the convent of Carthusians the shock from the discharge of a large Leyden jar was felt by every individual in a circuit which comprised 5,400 feet.

The bodies of animals killed by a powerful shock of electricity are found to undergo rapid putrefaction, and it is a remarkable fact that after death the blood does not coagulate.

When the Leyden phial was first discovered, it was imagined that an agent of almost unlimited medical power was raised, and it was applied indiscriminately for the cure of the most opposite diseases. The failures consequent on such quackery brought electricity into disrepute, and for a long time its use was almost discarded. It is now more generally employed, and has been found of service in many cases, such as in palsy, contractions of the limbs, rheumatism, St. Vitus's dance, some kinds of deafness, and impaired vision.

(36) **Chemical Effects.**—When a succession of electric discharges is sent through water, decomposition of that fluid takes place, the elements assuming the gaseous form. Dr. Wollaston, by sealing fine gold wires into glass tubes, and then grinding them down so as to disclose points from $\frac{1}{700}$th to $\frac{1}{1500}$th of an inch in diameter, found that sparks from a conductor passing through water from points so guarded to the distance of from $\frac{1}{8}$th to $\frac{1}{20}$th of an inch effected its decomposition.

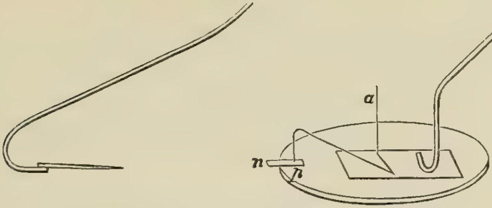
By passing a succession of shocks through a small quantity of water tinged blue by litmus, the liquid in a short time acquires a red tinge, while the air in the tube suffers a diminution. This experiment was first made by Priestley, but it was Cavendish who demonstrated that the reddening of the litmus was occasioned by the formation of nitric acid.

By the following instructive experiments it was shown by Faraday (*Ex. Research.*, Series v., pp. 1062 *et seq.*) that to effect chemical decomposition by frictional electricity, two *metallic poles* are not required, and that even *air* may act as a pole:—

1. A piece of turmeric paper 0·4 of an inch long and 0·3 of an inch wide was moistened with sulphate of soda, and placed upon the edge of a glass plate opposite to, and about two inches from, a point connected with a discharging train. A piece of tin-foil, resting upon the same glass plate

was connected with the machine and also with the turmeric paper by the decomposing wire *a*, Fig. 56. The machine was then worked, the positive

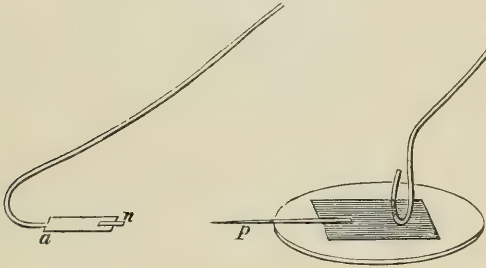
Fig. 56.



electricity passing into the turmeric paper at the point *p*, and out at the extremity *n*. After forty or fifty turns of a powerful machine, the extremity *n* was examined, and the two points or angles were found to be coloured *brown*, evincing the presence of free alkali, and consequently the decomposition of the sulphate of soda.

2. A similar piece of litmus paper dipped in a solution of sulphate of soda (Fig. 57) was now supported upon the end of the discharging train *a*, and

Fig. 57.



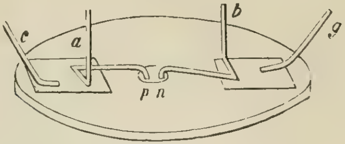
its extremity brought opposite to a point *p*, connected with the conductor of the machine. After a short time acid was developed at both corners towards the point, i.e. at both corners receiving electricity from the air. Then a long piece of turmeric paper, large at one end and pointed at the other, was moistened in the saline solution, and immediately connected with the conductor of the machine, so that its pointed extremity was opposite a point upon the discharging train. When the machine was worked alkali was evolved at that point; and even when the discharging train was removed, and the electricity left to be diffused and carried off altogether by the air, still alkali was evolved where the electricity left the turmeric paper.

The following arrangement was employed by Faraday for effecting polar electro-chemical decomposition by common electricity:—

On a glass plate raised above a piece of white paper, two small slips of

tin-foil, *a b*, were placed; one was connected by an insulated wire, *c*, with an electrical machine, and the other by the wire *g* with the negative con-

Fig. 58.



ductor. Two pieces of platinum wire were bent, and arranged so that the points *p n* became the decomposing poles. They were placed on a piece of filtering paper, wetted with the solution to be experimented upon. When litmus paper, moistened in a solution of common salt or sulphate of soda, was employed it was quickly reddened at *p*; a similar piece moistened in hydrochloric acid was very soon bleached at the same point, but no effects of a similar kind took place at *n*.

A piece of turmeric paper moistened in solution of sulphate of soda was reddened at *n* by two or three turns of the machine, and in twenty or thirty turns plenty of *alkali* was there evolved. On turning the paper round so that the spot came under *p*, and then working the machine, the alkali soon disappeared, the plate became yellow, and a brown alkaline spot appeared in the new part under *n*. When pieces of litmus and turmeric paper, both wetted with solution of sulphate of soda, were combined, and put upon the glass so that *p* was on the litmus and *n* on the turmeric, a very few turns of the machine sufficed to show the evolution of acid at the former and of alkali at the latter.

In these experiments the direct passage of sparks must be carefully avoided. If sparks be passed over moistened litmus paper it is reddened, and if over paper moistened with solution of iodide of potassium, iodine is evolved. But these effects must be distinguished from those due to electro-chemical powers or true *electrolytic* action, and must be carefully avoided when the latter are sought for. The effect just mentioned is occasioned by the formation of *nitric acid* by the chemical union of the oxygen and nitrogen of the air. The acid so formed is in a high state of concentration, and therefore reddens the litmus paper, and decomposes the iodide.

(37) **Magnetic Effects.**—The magnetic power of the frictional electric current, though far inferior to that of the voltaic current, is nevertheless decisive.

1. Lay an unmagnetised steel needle transversely on a strip of copper, a thin plate of glass or a piece of gutta-percha being interposed between the two; pass a few discharges from the Leyden phial along the copper, the needle will be found to have become magnetic; note the polarity given to the point of the needle, then make a similar experiment with another needle,

placing it *under* the copper plate ; the polarity will be found to be reversed. In the first experiment the end of the needle, which lay to the *right* of the electric current, will be a *north* pole; in the second experiment it will be a south pole.

2. Place an unmagnetised needle within a spiral of copper wire covered with silk; a few sparks from the prime conductor of a powerful machine will render it magnetic ; a charge from a Leyden phial, sent through the coil, will render it powerfully so. The needle being magnetised and its polarity noted, let it be replaced in the spiral, and transmit the electric current so that the north pole of the needle shall lie on the right hand of the direction in which the current moves ; after a few discharges the polarity of the needle will be reversed.

When a powerful discharge is determined through the wire of a galvanometer, the needle is deflected, but the effect is very feeble. A more satisfactory result is obtained when the end of the galvanometer wire is connected with the discharging rod by a wet string three or four feet long, the reason being, as in the case of the ignition of gunpowder, that the velocity of the discharge is thereby lessened. It results from the experiments of Faraday (*Ex. Research.*, Series iii., pp. 361 *et seq.*) that the deflecting force of an electric current is directly proportional to the absolute *quantity* of electricity passed, at whatever *intensity* that electricity may be.

Ex. *Eight* Leyden jars, arranged as a battery, were charged by thirty turns of a powerful machine, and discharged through the wire of a galvanometer, a thick wet string about ten inches long being included in the circuit. The needle was deflected five and a half divisions. *Seven* other equal-sized jars were then added, and the whole *fifteen* charged as before by thirty turns of the machine, the galvanometer needle passed exactly to the same division as in the former instance. The battery of *fifteen* jars was then charged by sixty revolutions of the machine, and discharged as before through the galvanometer ; the needle was now deflected to the eleventh division, an arc exactly double the former.

CHAPTER V.

ATMOSPHERIC ELECTRICITY.

Atmospheric Electricity—Annual and Diurnal Changes—Observations at Kew and Brussels—Instruments for Collecting and Examining Atmospheric Electricity—Thunder and Lightning—Lightning Conductors—Tornadoes—Waterspouts—The Aurora Borealis—Action of Atmospheric Electricity on the Wires of the Electric Telegraph.

(38) **The Atmosphere the great Natural Reservoir of Electricity.**—That part of our planet in which the electricity evolved by various processes accumulates is the *atmosphere* ; here it varies both in condition and in intensity. When the air is clear,

and the sky serene, it is generally positive; in damp or rainy weather, it is occasionally negative. It is more powerful in the higher regions than in the lower; it is stronger in winter than in summer; and when the air is still, it is more intense than during the prevalence of wind.

The transitions in the electrical state of the atmosphere were frequently observed by Humboldt during his travels in the equinoctial regions of the new continents.

'I saw on the banks of the River Apure,' he writes (*Travels*, vol. ii., p. 143), 'what I had often observed on the ridges of the Alps during a storm, that the electricity of the atmosphere was first positive, then *nil*, then negative. These oscillations from positive to negative were frequently repeated . . . . . . We noticed in the valleys of Aragua the increase of atmospheric electricity, with the augmentation of vesicular vapours; and the electrometer of Volta constantly displayed at sunset positive electricity. During whole hours in the daytime the electricity was *nil*, then it would become very strong, and soon after again imperceptible.'

(39) **Annual and Diurnal Changes.**—The *intensity* of the free electricity of the atmosphere increases from the month of July to the month of November, inclusive. It is also subject to diurnal variations, there being two *maxima* and two *minima* every twenty-four hours. The first minimum takes place a little before the rising of the sun; as it rises, the intensity at first gradually and then rapidly increases, and arrives at its first maximum a few hours after. This excess diminishes at first rapidly and afterwards slowly, and arrives at its minimum some hours before sunset. It reascends when the sun approaches the horizon, attains its second maximum a few hours after, then diminishes till sunrise, and proceeds in the order already indicated.

(*a*) *Observations at the Kew Observatory* (Ronalds).—A series of electrical readings was taken at the Kew Observatory during a period of three years and seven months, viz. from January 1844 to July 1848. The observations recorded amounted to 10,500; 10,176 of which were positive, and 324 negative. The greatest number of positive observations, viz. 1,047, were recorded at 8 A.M., and the least number, viz. 566, at 6 A.M.; the hour of minimum tension was 2 A.M., a gradual rise taking place from that hour until 6 A.M. Between the hours of 6 and 8 A.M. a rapid rise occurred, the tension being nearly doubled; it then increased gradually until 10 A.M., when a maximum was passed, after which it gradually declined until 4 P.M., the epoch of *diurnal* minimum as contradistinguished from the *nocturnal* minimum. The tension then rapidly increased until 8 P.M., and at 10 P.M. passed another maximum rather considerably above the maximum of 10 A.M. From 10 P.M. to midnight the diminution of tension was enormous

The midnight value was but slightly above the value at 2 A.M., the epoch of the minimum.

Of the 10,176 positive observations, 5,514 were taken in the summer months, and 4,662 in the winter months. Greater uniformity prevailed during the summer than during the winter, though there was a considerable diminution of tension between 10 P.M. and midnight; 2 A.M. was the epoch of the principal minimum, the tension gradually rising until 10 P.M., the forenoon maximum; the succeeding minimum occurred at noon, gradually rising till 6 P.M., and then rapidly till 10 P.M., the principal maximum, from which time till midnight the decline was very considerable. In the winter the range and amount of tension was much greater than in the summer; the minimum was at 4 A.M., rising gently to 6 A.M., and rapidly to 10 A.M., the forenoon maximum; then gradually sinking to 4 P.M., the afternoon minimum; and again rapidly rising till 8 P.M., the epoch of the evening maximum, the fall from which to midnight being enormous.

In both winter and summer a *double progression* was most distinctly exhibited. The points of maxima and minima were well marked, and in most cases a tolerable fixity of epoch was presented. The presence of fog, occurring mostly on those occasions when high electrical tensions were observed, and serene weather being mostly characterised by low tensions, suggested the probability that the forenoon and evening maxima result more or less from the presence of aqueous vapour, either in an invisible or in a condensed state.

The discussion (by Mr. Birt) of the whole series of observations discloses a march of electrical tension during the twenty-four hours constituting the period of a day. The march presents two well-defined maxima, in most instances removed from each other by an interval of twelve hours; the principal occurring at 10 P.M., and the inferior at 10 A.M. The principal minimum occurred at 4 A.M.; and the subordinate at 4 P.M. Speaking generally, in the *diurnal* period the periods characterised by high and low tensions are those at which the sun is above and below the horizon; but in the *annual* period the reverse appears to take place, the highest tension being exhibited during that portion of the year in which the sun is removed from the northern temperate zone. A general correspondence is shown as to the months exhibiting the greatest degree of humidity and the greatest electrical tension. The tension at sunset was, with but few exceptions, higher than at sunrise.

The majority of instances in which *negative* electricity was exhibited, were characterised by two very interesting features: one was the falling of heavy rain, and the other the occurrence of

cirro-strati and *cirro-cumuli*, which clouds were considered as having contributed their quota to the development of the electricity observed. The observations were too few to deduce a diurnal period for negative electricity, but they pointed out a connection between negative reading and the prevalence of clouds, and they revealed indications of considerable disturbances of a systematic character.

(*b*) *Observations at the Royal Observatory in Brussels* (Quetelet). —These were continued from the beginning of August 1844 till the end of December 1848. They show:—

1. That atmospheric electricity, considered in a general manner, attains its *maximum* in January, and progressively decreases till June, which month presents a *minimum* of intensity; it augments during the following months till the end of the year.

2. That the maximum and minimum of the year have for their respective values 605 and 47; so that the electricity in January is *thirteen* times more energetic than in the month of June.

3. That the difference between the maximum and minimum is much more sensible in serene than in cloudy weather, but that in the months of June and July, when the electricity attains its minimum, the reading is very nearly the same whatever be the state of the sky.

Quetelet also noticed a strong electricity, either positive or negative, at the approach or cessation of rain. During the whole four years included in his register, the electricity was observed to be *negative* only twenty-three times, and these indications either preceded or followed rain and storms.

The following conclusions, deduced by Quetelet from his observations made to ascertain the diurnal variations of atmospheric electricity, are in close accordance with those of Birt, as deduced from the Kew observations:—

1. The electricity of the air, estimated always at the same height, undergoes a diurnal variation, which generally presents two maxima and two minima.

2. The maxima and minima vary according to the different periods of the year.

3. The first maximum occurs in summer, before 8 A.M., and towards 10 A.M. in winter. The second maximum is observed after 9 P.M. in the evening in summer, and towards 6 P.M. in winter. The interval of time which separates the two minima is therefore more than thirteen hours at the epoch of the summer solstice, and eight hours only at the winter solstice.

4. The minimum of the day presents itself towards 3 o'clock in the summer, and towards 1 o'clock in winter.

5. The instant which best represents the mean electric state of the day in the different seasons occurs about 11 A.M.

(40) **Observations of Beccaria and Thomson.**—Beccaria has remarked on the rare occurrence of *negative* atmospheric indi-

cations during fair weather: during a period of fifteen years he recorded the electrical state of the atmosphere negative only *six* times; but Thomson found, on several days of fair unbroken weather in April and May, negative atmospheric indications during short periods, and on each occasion there was a sudden change in the wind—generally from NE. to NW., W., or SW.

Thomson explains the reversed electric indications observed about the time of a change of wind in the following manner:—

The lower air up to some height above the earth must in general be more or less electrified with the same kind of electricity as that of the earth's surface; and since this reaches a high degree of intensity on every tree-top and pointed vegetable fibre, it must always cause more or less of the phenomenon which becomes conspicuous as the light of Castor and Pollux, known to the ancients, or the fire of St. Elmo, described by modern sailors in the Mediterranean, and which consists of a flow of electricity, of the kind possessed by the earth, into the air. Hence in fair weather the lower air must be *negative*, although the atmospheric *potential* even close to the earth's surface is still generally positive. But if a considerable area of this lower stratum is carried upwards into a column over any locality, by wind blowing inwards from different directions, its effects may for a time predominate, and give rise to a *negative* potential in the air, and a positive electrification of the earth's surface. If this explanation be correct, a whirlwind (such as is often experienced on a small scale in hot weather) must diminish and may reverse the ordinary positive indications.

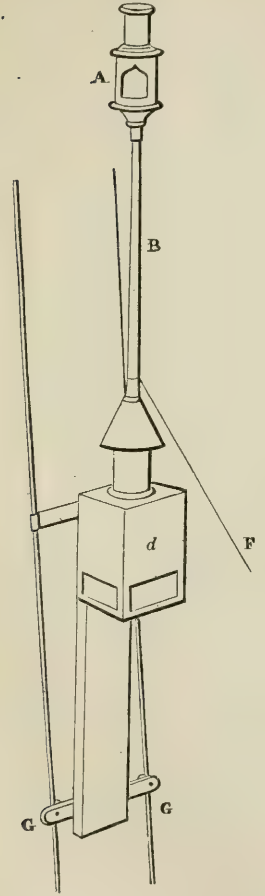
(41) Instruments for Examining the Electrical Condition of the Lower Atmosphere.

1. *The Exploring Conductor at Kew Observatory.*—This is a conical tube of thin copper raised 16 feet above the dome of the building, carrying at the top a small lantern or collecting lamp, provided with a little cowl, which can be raised or lowered at pleasure by means of a silk cord. The conductor is firmly screwed into a strong brass tube which is cemented to a well-annealed hollow glass pillar, the lower end of which is trumpet-shaped and ground flat, and is firmly secured to a pedestal. The glass tube is kept constantly warmed by a small oil lamp, the closed copper chimney of which enters but does not actually touch it. The brass tube carries at its lower end three or four arms, at right angles to each other, with which the electrometers and other electrical apparatus are connected. The conductor at the point where it enters the dome is protected from the weather by an inverted copper disk. By this mode of arrangement the active parts of all the electrometers and he conductor itself are insulated by one common and efficient insulator. A safety conductor in good communication with the earth is attached to the pedestal.

2. *The Exploring Conductor at the Greenwich Observatory.*—This is arranged in a similar manner: B (Fig. 59) is the copper tube, on which the lantern, containing a lamp (A) which is always burning, slides. The rod is supported on a cone of glass, the lower part of which is hollowed out and lined with copper; immediately under which is, in the wooden apparatus *d*, placed a lamp, which is kept constantly burning, for the purpose of heating the copper, and thus keeping the glass dry. The glass cone is pro-

tected from rain by a copper umbrella, from which proceeds the wire F, communicating with the electrical instruments in the anteroom.

Fig. 59.



3. *The Electrometers.*—The observations at Kew and Greenwich were taken with a Henley's electrometer, by which the force is measured by a straw, terminating in a pith-ball, which together constitute a pendulum that is inserted in a ball working by two fine steel pivots ; and by Volta's electrometers, *two* in number. No. 1 is so constructed that a given electric force causes a pair of straws of known weight to diverge. Their divergence is measured on a circular arc of the same radius as the lengths of the straws, which is so graduated as to indicate half the distance in arc between the extremities of the straws in half Parisian lines, each of the divisions, which are at equal distances from each other, being equal to half a line. It is clear from this construction, that upon measuring the distance between the straws in a right line, '*the line of half the angle subtended by the extremities of the straws is proportional to the electric tension of the charge.*'

No. 2 electrometer was so constructed that each division was exactly equal to *five* of No. 1 ; and the circular arc is graduated to read at once in terms of No. 1. The difference in the electrometers consists in the straws of No. 2 being heavier than those of No. 1, in such proportion as to increase the value of the readings in the ratio above mentioned. As in No. 1 the sine of half the angle of divergence is proportional to the tension, so in No. 2 precisely the same value of the tension obtains—viz. the sine of half the angle of divergence, the linear value of the sine itself being proportional to its value in No. 1 for the same force : thus a force that would diverge the straws in No. 1 to an angle of 30° would only open those in No. 2 to an angle of 6°, and in each instrument the sine of 15° and 3° respectively would represent the force. One degree of Henley's electrometer is nearly equal to 100° of Volta No. 1 ; and by converting the readings of the latter into measures of arc, Volta No. 1, Volta

No. 2, and Henley's may all be expressed in degrees of the circle, the sines of which are readily ascertainable.

The Volta electrometers are placed on the table of the pedestal, with their caps in contact with the conductor, and the Henley's electrometer is screwed into a ball fixed at the extremity of one of the horizontal arms.

4. *The Gold-Leaf Electroscope.*—The wire A (Fig. 60), terminating in a pair of forceps, which carry the paper to which the gold leaves are suspended, passes through the glass stopper B, which is ground into a long-necked bottle C, with a metallic base D; and a strip of brass, E E, is bent and screwed to the inside of D. The neck C is well covered with sealing

Fig. 60.

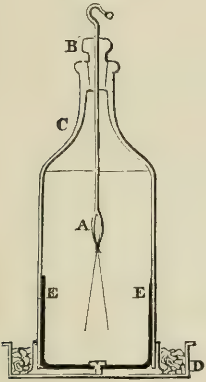
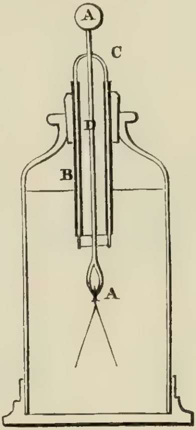


Fig. 61.

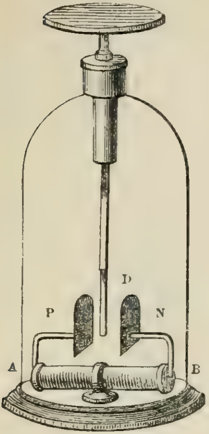


wax both inside and out. To preserve the insulating power of the instrument, it is surrounded at its base with an annular tin trough, coated with sealing wax, and containing chloride of calcium, the whole being covered air-tight with a receiver.

5. *The Distinguisher* (Fig. 61).—This is a very thin Leyden phial, C. A is a wire, connected with a brass tube which forms the interior coating of this jar; and B is an exterior coating of the same kind; and these two coatings are at about three-fourths of an inch distant from each extremity of the phial. The intervals D C, B C are coated with sealing wax inside and out. A thus prepared is fitted to a bottle with a metallic base, and is provided with a pair of gold leaves rather too short to reach the sides of the bottle, the neck of which, both inside and out, is covered with sealing wax. The distinguisher is charged every morning *negatively*, and never fails to retain a good charge for twenty-four hours. It is conveniently placed on a bracket a few feet distant from the conductor, to which when used it is approached by the hand to some distance proportionate to the height of the charge. If the charge be positive, the leaves of course collapse more or less, but open again when the instrument is withdrawn; if the

charge be negative, the divergence of the leaves increases, and the operation can be performed without the least danger of lowering the tension of the conductor, or injuring the gold leaves, let the height of the charge be what it may.

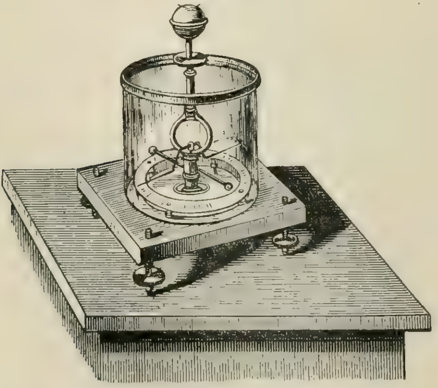
Fig. 62.



6. *Bohnenberger's Electroscope.*—This instrument is shown in Fig. 62. A B is a dry electric column (the construction of which will be described hereafter), consisting of about 500 pairs, each about one-fourth of an inch in diameter, and occupying, when the plates are pressed together, from two to two inches and a half in length. To the ends of this pile are adapted two bent wires, terminating in two gilded plates P N, which constitute the poles of the battery. These plates, which are two inches long and half an inch wide, are parallel and opposite to each other, the gold leaf D being suspended between them. Now if the leaf hangs exactly midway between the terminal plates of the column, it will be equally attracted by each, and will therefore remain in a state of repose; but the most minute quantity of electricity communicated to the cap of the instrument will disturb this neutral condition of the leaf, and it will immediately move towards the plate which has the opposite polarity.

7. *Peltier's Electrometer.*—In this instrument (shown in Fig. 63) the directive force exerted by the earth upon a small magnet is

Fig. 63.



substituted for the torsion of the wire in Coulomb's torsion elec-

trometer (Fig. 6, p. 6). A small magnetised needle is supported upon a long brass wire, which moves freely on a pin like a compass needle; a stout metallic rod, terminated above by a ball, passes through a glass shade, and is cemented into a disc of ebonite, which forms the base of the instrument. This rod is expanded into a ring wide enough to allow free motion within it of the small magnetic needle. The ring carries two brass arms. To use the instrument, it is placed so that when in the magnetic meridian the brass wire on which the magnetic needle is supported just touches the two fixed arms of the brass ring. On communicating a charge of electricity to the ball, it spreads over the insulated wire and movable needle, which is immediately deflected by the fixed arms of the brass ring, and the amount of angular deviation gives the means of estimating the force. In Messrs. Elliot's mode of constructing the electrometer, the needle and repelling plates are insulated by a composition of gum-damar and Venetian turpentine. They retain a nearly constant charge for some time, unaided by an artificially-dried atmosphere; at the end of twenty-four hours the deflection due to the charge will frequently be found not to have fallen more than one-half.

(42) **Professor William Thomson's Electrometers.**—(I.) *The Divided-Ring Electrometer.*—The following is the principle of the construction of this instrument:—

A glass tube, about a foot long, is arranged as an inverted Leyden jar. In the inside, and in metallic connection with the inner coating, is suspended, by a fine platinum wire, an aluminium needle and a mirror. The former swings in a divided box, consisting of a hollow cylinder of brass, divided parallel to its axis. Both parts are insulated from each other, and from the other part of the instrument. The mirror connected with the needle is placed in such a manner that a ray of light thrown on it is reflected upon a cylinder.

A considerable quantity of pumice-stone, moistened with sulphuric acid, keeps the inside of the instrument perfectly dry; and when the Leyden jar is charged, the needle is thrown into a highly electrified state, and consequently is much more sensitive to electric influence. Now, if one part of the divided box is connected with the earth, and the other with a large insulated vessel of water, constantly discharging a fine jet into the air (43), the electricity of the atmosphere is communicated to it, and attracts or repels the suspended needle, as the case may be. Outside the instrument, on the same level as the mirror attached to the needle, a second fixed mirror is placed, which reflects the light of a lamp upon the cylinder above mentioned, which is covered with photo-

graphic paper, and moved by clockwork, and can be made to revolve once in twelve, eighteen, or twenty-four hours, by inserting different wheels.

A cylindrical lens converts the reflected image of the lamp into two spots of light, which are superposed when the needle is at rest. The reflection of the fixed mirror photographs on the cylinder, when set in motion, a straight line—the zero line. The mirror connected with the needle records on the cylinder the variations of electric tension in the atmosphere in a manner similar to the self-recording magnetometer. Two gauges, in the shape of fans, enable the observer to determine the loss of charge in the Leyden jar within twenty-four hours.[1]

(II.) *The Common House Electrometer.*—This instrument consists of—

1. A thin flint glass bell, coated outside and inside like a Leyden phial, with the exception of the bottom inside, which contains a little sulphuric acid.

2. A cylindrical metallic case, enclosing the glass jar, cemented to it round its mouth outside, extending upwards about an inch and a half above the mouth, and downwards to a metal base supporting the whole instrument, and protecting the glass against the danger of breakage.

3. A cover of plate-glass with a metal rim, closing the top of the cylindrical case of the instrument.

4. A torsion head, after the manner of Coulomb's balance (Fig. 6, p. 6), supported in the centre of the glass cover, and bearing a glass fibre, which hangs down through an aperture in its centre.

5. A light aluminium needle attached across the lower end of the fibre (which is somewhat above the centre of the glass bell), and a stiff platinum wire attached to it at right angles, and hanging down to near the bottom of the jar.

6. A very light platinum wire, long enough to hang within one-eighth of an inch or so of the bottom of the jar, and to dip in the sulphuric acid.

7. A metal ring attached to the inner coating of the jar, bearing two plates in proper positions for repelling the two ends of the aluminium needle when similarly electrified, and proper stops to limit the angular motion of the needle to within about 45° from these plates.

8. A cage of fine brass wire, stretched on brass framework, supported from the main case above by two glass pillars, and partially enclosing the two ends of the needle and the repelling plates, from all of which it is separated by clear spaces of nowhere less than one-fourth of an inch of air.

9. A charging electrode attached to the ring (7), and projecting over the mouth of the jar to the outside of the metal case (2) through a wide aperture, which is commonly kept closed by a metal cap, leaving at least one-quarter of an inch of air round the projecting end of the electrode.

10. An electrode attached to the cage (8), and projecting over the mouth

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[1] For the above description of this beautiful instrument we are indebted to the late Mr. Becker, of the firm of Messrs. Elliot and Co., the makers of the instrument, from whom further particulars respecting it may be obtained.

of the jar to the outside of the metal case (2) through the centre of an aperture about a quarter of an inch in diameter.

This instrument is adapted to measure differences of 'potential' between two conducting systems—namely, as one, the aluminium needle (5), the repelling plates (7), and the inner coating of the jar; and as the other, the insulated glass cage (8). This latter is commonly connected by means of its projecting electrode (10) with the conductor to be tested. The two conducting systems, if through their projecting electrodes connected by a metallic wire, may be electrified to any degree without causing the slightest sensible motion in the needle. If, on the other hand, the two electrodes of these two systems are connected with two conductors, electrified to different potentials, the needle moves away from the repelling plates; and if by turning the torsion head it is brought back to one accurately-marked position, the number of degrees of torsion required is proportional to the *square* of the difference of potentials thus tested.

In the ordinary use of the instrument, the inner coating of the Leyden jar is charged *negatively* by an external application of electricity through its projecting electrode (9). The degree of the charge thus communicated is determined by putting the cage in connection with the earth through its electrode (10), and bringing the needle by torsion to its marked position. The *square root* of the number of degrees of torsion required to effect this measures the 'potential' of the Leyden charge. This result is called *the reduced earth-reading.* When the atmosphere inside the jar is kept sufficiently dry, this charge is retained from day to day with little loss—not more often than one per cent. in twenty-four hours.

In using this instrument, the charging electrode (9) of the jar is left untouched, with the aperture through which it projects closed over it by the metal cap referred to above. The electrode (10) of the cage, when an observation is to be made, is connected with the conductor to be tested, and the needle is brought by torsion to its marked position. The square root of the number of degrees of torsion now required measures the difference of potentials between the conductor tested and the interior coating of the Leyden jar. The excess, positive or negative, of this result above the reduced earth-reading measures the excess of the 'potential,' positive or negative, of the conductor tested above that of the earth; or simply the potential of the conductor tested, if we regard that of the earth as zero.

(43) **Thomson's Simple Apparatus for Observing Atmospheric Electricity.**—It consists of an insulated can of water to set on a table or window-sill *inside*, and discharge by a small pipe

through a fine nozzle two or three feet from the wall. With only about ten inches head of water, and a discharge so slow as to give no trouble in replenishing the can with water, the atmospheric effect is collected so quickly that any difference of potentials[1] between the insulated conductor and the air, at the place where the stream from the nozzle breaks into drops, is done away with at the rate of five per cent. per half-second, and even faster. Hence a very moderate degree of insulation is sensibly as good as perfect, as far as observing the atmospheric effect is concerned.

By drying the atmosphere round the insulating stems by means of pumice-stone, moistened with sulphuric acid, a high degree of insulation may be insured in all weathers, but it is necessary to keep the outer part of the apparatus clear of spider-lines.

An apparatus constructed on this principle was employed by Thomson in some examinations of atmospheric electricity at Invercloy. It stood on a table beside a window on the second-floor, which was kept open about an inch to let the discharging tube project out without coming into contact with the frame. The nozzle was only about $2\frac{1}{2}$ feet from the wall, and nearly on a level with the window-sill. The *divided-ring electrometer* (42 I.) stood on the table beside it; it acted remarkably well, being supplied with a Leyden phial, consisting of a common thin white glass shade instead of a German glass jar, which Thomson found not to hold its charge well.

The index required $13\frac{1}{2}°$ to $14°$ of torsion to bring it to zero, when urged aside by the electro-motive force of 10 cells of zinc and copper charged with water only. The atmospheric effect ranged from $30°$ to about $420°$ during the four days of the experiment; that is to say, the electro-motive force per foot of air, measured horizontally from the side of the house, was from 9 to 126 zinc copper water-cells. The weather was almost perfectly settled, either calm or with slight east wind. The electrometer, twice within half an hour, went above $420°$, there being at the time a fresh temporary breeze from the east.

What Thomson had previously observed regarding the effect on an east wind was amply confirmed. Invariably the electrometer showed very high *positive* in fine weather before and during east wind. It generally rose very much shortly before a slight puff of wind from that quarter, and continued high till the wind would begin to abate. The electrometer was never observed to go up unusually high during fair weather without east wind following immediately.

Cloudy masses of air at no great distance from the earth, certainly not more than a mile or two, influence the electrometer largely by the electricity they carry.

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[1] The term *electric potential* is defined by Prof. Wm. Thomson as follows:—'The *potential*, at any point in the neighbourhood of or within an electrified body, is the quantity of work that would be required to bring a unit of positive electricity from an infinite distance to that point, if the given distribution of electricity remained unaltered.' (Paper read before the British Association, 1852.)

(44) **Exploring Wires.**—The late Mr. Crosse and the late Mr. Weekes examined the electrical condition of the lower regions of the atmosphere, the former at Broomfield in Somersetshire, and the latter at the town of Sandwich, by means of exploring wires insulated on appropriate supports. At Broomfield, the wires extending to many hundred yards were attached to poles fixed on trees; at Sandwich the wire was extended between the vane-spindles of two churches, through a length of 365 yards.

Mr. Crosse gives the following account of the phenomena observed on the approach of a thunder-cloud to his exploring wire:—

'When the cloud draws near, the pith-balls suspended from the conductor open wide, with either positive or negative electricity; and when the edge of the cloud is perpendicular to the exploring wire, a slow succession of discharges takes place between the brass ball of the conductor and one of equal size carefully connected with the nearest spot of moist ground. I usually connect a large jar with the conductor, which increases the force and in some degree regulates the number of explosions; and the two balls, between which the discharges pass, can be easily regulated as to their distance from each other by a screw. After a certain number of explosions, say of *negative* electricity, which at first may be nine or ten a minute, a cessation occurs of some seconds or minutes, as the case may be, when about an equal number of explosions of *positive* electricity takes place, of similar force to the former, *indicating the passage of two oppositely and equally electrified zones of cloud.* Then follows a second zone of *negative* electricity, occasioning several more discharges in a minute than from either of the first pair of zones, which rate of increase appears to vary according to the size and power of the cloud. Then occurs another cessation, followed by an equally powerful series of discharges of *positive* electricity, indicating the passage of a second pair of zones; these in like manner are followed by others, fearfully increasing in the rapidity of the discharges, when a *regular stream* commences, interrupted only by the change into the opposite electricities. The intensity of each new pair of zones is greater than that of the former, as may be proved by removing the two balls to a greater distance from each other. When the centre of the cloud is vertical to the wire, the greatest effect takes place, during which *the windows rattle in their frames*, and the bursts of thunder without and the noise within, every now and then accompanied with a crash of accumulated fluid in the wire, striving to get free between the balls, produce the most awful effect, which is not a little increased by the pauses occasioned by the interchange of zones.

'As the cloud passes onward, the opposite portions of the zones which first affected the wire come into play; and the effect is weakened with each successive pair, till all dies away, and not enough electricity remains in the atmosphere to affect a gold-leaf electroscope.'

(45) **Electrical Fog.**—Of the electrical phenomena attending a dense November fog Mr. Crosse furnished the author with the following graphic description:—

'Many years ago I was sitting in my electrical room on a dark November day, during a very dense driving fog and rain, which had prevailed for many hours, sweeping over the earth, and impelled by a south-west wind. The mercury in the barometer was low, and the thermometer indicated a low temperature. I had at this time 1,600 feet of wire insulated, which, crossing two small valleys, brought the electric fluid into my room. There were four insulators, and each of them were streaming with wet from the effects of the driving fog. From about 8 A.M. until 4 P.M. not the least appearance of electricity was visible at the atmospheric conductor, even by the most careful application of the condenser and multiplier; indeed, so effectually did the exploring wire conduct away the electricity which was communicated to it, that when it was connected, by means of a copper wire, with the prime conductor of an 18-inch cylindric electrical machine in high action, and a gold-leaf electroscope placed in contact with the connecting wire, not the slightest effect was produced upon the gold leaves. Having given up the trial of further experiments, I took a book and occupied myself with reading, leaving by chance the receiving ball upwards of an inch distant from the ball of the atmospheric conductor. About 4 P.M. I suddenly heard a very strong explosion between the two balls, and shortly after many more took place, until they became one uninterrupted stream of explosions, which gradually died away, and then recommenced with the opposite electricity in equal violence. The stream of fire was too vivid to look at for any length of time, and the effect was most splendid, continuing without intermission, save that occasioned by the interchange of electricities, for upwards of *five hours*, and then totally ceased.'

(46) **Mode of Examining the Electrical Condition of the Higher Regions of the Atmosphere.**—For this purpose the Franklinian kite may be employed, but great care is requisite in conducting the experiments, as severe shocks may be received from the string, even under a clear and cloudless sky. The late Mr. Sturgeon had, however, the boldness to send up a kite during a thunderstorm, and he has given the following description of the phenomena he observed:—

'The wind had abated to such a degree, and the rain fell so heavily, that it was with some difficulty that I got the kite afloat, and when up its greatest altitude did not exceed fifty yards. The silken cord also, which had been intended for the insulator, soon became so completely wet that it was no insulator at all. Notwithstanding all these impediments being in the way, I was much gratified with the display of the electric matter issuing from the end of the string to a wire, one end of which was laid on the ground and the other attached to the silk, at about four inches' distance from the reel of the kite-string; an uninterrupted play of the fluid was seen over the four inches of wet silken cord, not in sparks, but in a bundle of quivering purple ramifications, producing a noise similar to that of a watchman's rattle. Very large sparks, however, were frequently seen between the lower end of the wire, which rested on the grass and the ground; and several parts of the string towards the kite, where the wire was broken, were occasionally beautifully illuminated. The noise from the string in the air was

like to the hissing of an immense flock of geese, with an occasional rattling or scraping noise.

'The reel was occasionally enveloped in a blaze of purple arborised electrical fire, whose numberless branches ramified over the silken cord and through the air to the blades of grass, which also became luminous on their points and edges over a surface of some yards in circumference. We also saw a complete globe of fire pass over the silken cord between the wire and the reel of the kite-string; it was exceedingly brilliant, and the only one that we noticed.'

It is sometimes necessary to penetrate regions of the atmosphere beyond the height attainable by a single kite, before signs of electricity can be obtained; this may be done by letting two, three, or more kites fly from the same string. The first kite is sent up as usual, and when it has reached its maximum elevation the end of its string is put through a slit in the middle stick of the second, and tied to its string; the second kite is then raised; in like manner a third may be added, and thus great heights may be reached. The highest kite is almost invariably *positive* to the other two; the centre kite *positive* to the one below it, and the lowest *positive* to the ground.

(47) **Thunder and Lightning.**—The analogy between the electric spark and lightning was noticed at an early period of electrical science. In 1708 Dr. Wall pointed out a resemblance between them. In 1735 Grey *conjectured* their identity, and that they differed only in *degree*; and in 1748 the Abbé Nollet reproduced the conjecture of Grey, attended with more substantial reasons; but it was reserved for the great American philosopher Franklin, in June 1752, to *demonstrate* the identity by the bold experiment of bringing down lightning from the heavens by means of a kite, and by performing with it experiments similar to those usually made with ordinary electricity.

The following is the account transmitted to us of this grand experiment:—

'He prepared his kite by making a small cross of two light strips of cedar, the arms of sufficient length to extend to the four corners of a large silk handkerchief stretched upon them to the extremities of the arms of the cross he tied the corners of the handkerchief. This being properly supplied with a tail, loop, and string, could be raised in the air like a common paper kite; and being made of silk, was more capable of bearing rain and wind. To the upright arm of the cross was attached an iron point, the lower end of which was in contact with the string by which the kite was raised, which was a hempen cord. At the lower extremity of this cord, near the observer, a key was fastened; and in order to intercept the electricity in its descent, and prevent it from reaching the person who held the kite, a silk ribbon was tied to the ring of the key, and continued to the hand by which the kite was held.

'Furnished with this apparatus, on the approach of a storm he went out upon the common near Philadelphia, accompanied by his son, to whom alone he communicated his intentions, well knowing the ridicule which would have attended the report of such an attempt should it prove to be unsuccessful. Having raised the kite, he placed himself under a shed, that the ribbon by which it was held might be kept dry, as it would become a conductor of electricity when wetted by rain, and so fail to afford that protection for which it was provided. A cloud, apparently charged with thunder, soon passed directly over the kite. Franklin observed the hempen cord; but no bristling of its fibres was apparent, such as was wont to take place when it was electrified. He presented his knuckle to the key, but not the smallest spark was perceptible. After the lapse of some time, however, he saw that the fibres of the cord near the key bristled and stood on end. He presented his knuckle to the key, and received a strong bright spark. *It was lightning.* A shower now fell, which, wetting the cord of the kite, improved its conducting power; sparks in rapid succession were drawn from the key; a Leyden jar was charged by it, and a shock was given: in fine, all the experiments which were wont to be made by electricity were reproduced identical in all their concomitant circumstances.'

It appears that the first spark from an atmospheric exploring apparatus was obtained by M. Dalibard, at Marly-la-Ville, one month before Franklin's kite experiment in America, but as his arrangements were made at the suggestion and on the principles of Franklin, it is unquestionably to the latter the honour of having established the identity between electricity and lightning must be awarded.

Franklin's experiment was eagerly repeated in almost every civilised country, and with variable success. In France a grand result was obtained by Romas, who constructed a kite seven feet high, which he raised to the height of 550 feet by a string having a fine wire interwoven throughout its whole length. It is stated that on the 26th of August, 1756, flashes of fire *ten feet long* were given off from this conductor. In 1753, Professor Richmann, of St. Petersburg, was struck dead by a flash of lightning from an exploring apparatus he had erected for the purpose of repeating Franklin's experiments.

Lightning and thunder, then, are atmospheric electrical phenomena, and a thunderstorm is the result of an electrical disturbance arising from the accumulation of active electricity in masses of vapour condensed in the atmosphere. Agreeably with the laws of induction, a mass of electrified vapour determines an opposite electrical state over that portion of the earth's surface directly opposed to it: the particles of intervening air assume a peculiar forced electrical state which has been termed '*polarised*,' and when the tension has been raised to a certain point, and the particles can no longer resist the tendency of the opposite electrical forces

to combine, they are displaced and broken through with a greater or less degree of mechanical violence. The clouds and the earth, or two oppositely electrified clouds, correspond to the coatings, and the intervening air to the glass of the Leyden phial, and the thunderstorm is the charging and discharging of this huge system.

The snap attending the spark from the prime conductor, and the awful thunder-crash, are undoubtedly similar phenomena, and produced by the same action. The cause is the vibration of the air, agitated by the passage of the electric discharges with a greater or less degree of intensity; and two explanations may be given of the manner in which the vibration is produced. On the one hand, it may be imagined that the electric fluid opens for itself a passage through air, or other matter, in the manner of a projectile, and that the sound is caused by the rush of the air into the vacuum produced by the instantaneous passage of the fluid; or, on the other hand, the vibration may be referred to a decomposition and recomposition of electricity, in all the media in which it appears. On this hypothesis the continued roll is the effect of the comparatively slow propagation of sound through air.

The latter of these two ways of accounting for the vibration seems to accord best with facts; for, in the first place, it has been objected, that if the noise were occasioned by the electric fluid forcing for itself a passage through the air, a similar sound ought to be produced by a cannon ball; and a still stronger objection is, that experiments seem to indicate that the electric fluid is not transferred from point to point like a projectile of ponderable matter, but by the vibration of an elastic medium.

(48) **Phenomena of a Thunderstorm.**—The appearance of the heavens previous to and during a thunderstorm was thus described by Beccaria (*Lettere dell' Elettricismo,* Bologna, 1758):—

'A dense cloud is first formed, increasing rapidly in magnitude, and ascending into the higher regions of the atmosphere. The lower end is black and nearly horizontal, but the upper end is finely arched and well-defined. Many of these clouds often seemed piled one upon the other, all arched in the same manner; but they keep constantly uniting, swelling, and extending their arches. When such clouds rise, the firmament is usually sprinkled over with a great number of separate clouds of odd and bizarre forms, which keep quite motionless. When the thunder-clouds ascend, these are drawn towards it, and as they approach they become more uniform and regular in their shapes, till coming close to the thunder-cloud their limbs stretch mutually towards each other, finally coalesce, and form one uniform mass. But sometimes the thunder-cloud will swell and increase without the addition of these smaller clouds. Some of the latter appear like white fringes at the skirts of the thunder-cloud, or under the body of it; but they continually grow darker and darker as they approach it.

'When the thunder-cloud thus augmened has attained a great magni-

tude, its lower surface is often ragged, particular parts being detached towards the earth, but still connected with the rest. Sometimes the lower surface swells into large protuberances, tending uniformly towards the earth; but sometimes one whole side of the cloud will have an inclination to the earth, which the extemity of it will nearly touch. When the observer is under the thunder-cloud after it is grown larger and is well formed, it is seen to sink lower and to darken prodigiously; and at the same time a great number of small clouds are observed in rapid motion, driven about in irregular directions below it. While these clouds are agitated with the most rapid motions, the rain generally falls in abundance; and if the agitation be very great it hails.

'While the thunder-cloud is swelling and extending itself over a large tract of country, the lightning is seen to dart from one part of it to another, and often to illuminate its whole mass. When the cloud has acquired a sufficient extent, the lightning strikes between the cloud and the earth in two opposite places, the path of the lightning lying through the whole body of the cloud and its branches. The longer this lightning continues, the rarer does the cloud grow, and the less dark in its appearance, till it breaks in different places and shows a clear sky. When the thunder-cloud is thus dispersed, those parts which occupy the upper regions of the atmosphere are spread thin and equally; and those that are beneath are black and thin also, but they vanish gradually without being driven away by the wind.'

A great difference will be observed in the appearance of the flashes of lightning during a thunderstorm. The scene is sometimes rendered awfully magnificent by their brilliancy, frequency, and extent; darting sometimes on broad and well-defined lines from cloud to cloud, and sometimes shooting towards the earth; they then become zigzag and irregular, or appear as a large and rapidly moving ball of fire, an appearance usually designated by the ignorant a *thunderbolt*, and erroneously supposed to be attended by the fall of a solid body. The report of the thunder is also modified according to the nature of the country, the extent of the air through which it passes, and the position of the observer. Sometimes it sounds like the sudden emptying of a large cart-load of stones, sometimes like the firing of a volley of musketry; in these cases it usually follows the lightning immediately, and is near at hand. When more distant, it rumbles and reverberates at first with a loud report, gradually dying away, and returning at intervals, or roaring like the discharge of heavy artillery.

In accounting for these phenomena, it must be remembered that the passage of electricity is almost infinitely rapid. A discharge through a circuit of many miles has been experimentally proved to be instantaneous. The motion of light is similarly rapid, and hence the flash appears momentary, however great the distance through which it passes; but sound is vastly slower in its progress, travelling in air, according to the most recent experiments of the members of the Paris Board of Longitude, 1,115 feet in a

second at 60 deg. Fahr. Now supposing the lightning to pass through a space of some miles, the explosion will be first heard from the point of the air agitated nearest the spectator, it will gradually come from the more distant parts of the course of the electricity, and last of all it will be heard from the remote extremity; and the different degrees of agitation of the air, and likewise the difference of the distance, will account for the different intensities of the sound and the reverberation.

Thomson has had several opportunities of observing electrical indications with his portable electrometer (43) during day thunderstorms. He commenced the observation on each occasion after having heard thunder and perceived frequent impulses on the needle, which caused it to vibrate, indicating sudden changes of electric 'potential' at the place where he stood. He could connect the larger of these impulses with thunder heard some time later, with about the same degree of certainty as the brighter flashes of lightning during a thunderstorm by night are usually recognised as distinctly connected with the distant peals of thunder. By counting time, he estimated the distance of the discharge as not nearer on any occasion than about four or five miles. On none of these occasions did he see any lightning.

The absolute 'potential' at the position of the burning match was sometimes positive and sometimes negative, and the sudden changes demonstrated by the impulses on the needle were, so far as he could judge, as often augmentations of positive or diminutions of negative as diminutions of positive or augmentations of negative.

(49) **Varieties of Lightning.**—Arago divides the phenomena of lightning into three classes. In the first he places those luminous discharges characterised by a long streak of light, very thin, and well-defined at the edges; they are not always white, but are sometimes of a violet or purple hue; they do not move in a straight line, but have a deviating track of a zigzag form. They frequently divide in striking terrestrial objects into two or more distinct streams, but invariably proceed from a single point.

Under the second class Arago has placed those luminous effects not having any apparent depth, but expanding over a vast surface. They are frequently coloured blue, red, and violet; they have not the activity of the former class, and are generally confined to the edges of the cloud from which they appear to proceed.

In the third class are included those more concentrated masses of light which Arago terms '*globular*' lightning. The long zigzag and expanded flashes exist but for a moment, but these seem to endure for many seconds; they appear to occupy time, and to have a progressive motion.

'It is more than probable,' observes Sir William Snow Harris (*Essay on the Nature of Thunderstorms*), 'that many of these phenomena are at last reducible to the common progress of the disruptive discharge modified by the quantity of passing electricity, the density and condition of the air, and the brilliancy of the attendant light. When the state of the atmosphere is such that a moderately intense discharge can proceed in an occasionally deviating zigzag line, the great nucleus or head of the discharge becomes drawn out as it were into a line of light visible through the whole track; and if the discharge divides on approaching a terrestrial object, we have what sailors call "*forked lightning*;" if it does not divide, but exhibits a long rippling line with but little deviation, they call it "*chain lightning*." What sailors term "*sheet lightning*" is the light of a vivid discharge, reflected from the surface of distant clouds, the spark itself being concealed by a dense intermediate mass of cloud, behind which the discharge has taken place. In this way an extensive range of cloud may appear in a blaze of light, producing a truly sublime effect. The appearance termed "*globular lightning*" may be the result of similar discharges; it is, no doubt, always attended by a diffusely luminous track: this may, however, be completely eclipsed in the mind of the observer by the great concentration and density of the discharge in the points immediately through which it continues to force its way, and where the condensation of the air immediately before it is often extremely great. It is this intensely luminous point which gives the motion of globular discharges; and it is clear, from the circumference of air which may become illuminated, that the apparent diameter will often be great.'

In many cases in which distinct balls of fire of sensible duration have been perceived, the appearance may have resulted from a species of brush (20, *b.*) or glow (20, *c.*) discharge, and it is not difficult to conceive that before a discharge of the whole system takes place—that is to say, before the constrained condition of the dielectric particles of air intermediate between the clouds and the earth becomes as it were overturned—the particles nearest one of the terminating plains or other bodies situate on them may begin to discharge upon the succeeding particles, and make an effort to restore the natural condition of the system by a *gradual* process.

(50) **Positions of Safety during a Thunderstorm.**—If out of doors, trees should be avoided; and if, from the rapidity with which the explosion follows the flash, it should be evident that the electric clouds are near at hand, a recumbent position on the ground is the most secure. It is seldom dangerous to take shelter under sheds, carts, low buildings, or the arch of a bridge; the distance of twenty or thirty feet from all tall trees or houses is rather an eligible situation, for should a discharge take place, these elevated bodies are most likely to receive it, and less prominent bodies in the neighbourhood are more likely to escape. It is right to avoid *water*, for it is a good conductor, and the height of a human being near the stream is not unlikely to determine the direction of a discharge. Within doors we are tolerably safe in

the middle of a carpeted room, or when standing on a double hearth-rug. The chimney should be avoided, as, when a building is struck with lightning, the charge is generally determined towards it, in consequence of the good conducting power of the carbon or soot; upon the same principle, gilt mouldings, bell wires, &c., are in danger of being struck. In bed we are tolerably safe, blankets and feathers being bad conductors, and we are consequently to a certain degree insulated. It is injudicious to take refuge in a cellar, for it has sometimes happened that buildings that have been struck by lightning have sustained the greatest injury in the basement story.

(51) **Back Stroke.**—A person may be struck by lightning although the explosion takes place twenty miles off, by what is called the 'back stroke.' Suppose that the two extremities of a cloud highly charged hang down to the earth; they will repel the electricity from the earth's surface if it be of the same kind as their own, and will attract the other kind; if a discharge should suddenly take place at one end of the cloud, the equilibrium will instantly be restored by a flash at that point of the earth which is under the other. Although this back stroke is sometimes sufficiently powerful to destroy life, it is never so terrible in its effects as the direct shock.

(52) **Lightning Conductors.**—Franklin was the first to suggest a method of defending buildings from the effects of lightning. His plan was to erect by the side of the building a continuous metallic rod in perfect communication with the earth, and experience has fully demonstrated the value of this precaution. The metal should be copper; the rod, about one inch in diameter, should be carried above the highest point of the building, and it should penetrate the ground sufficiently deep to come into contact with moist soil. It should be applied as closely as possible to the walls of the building, and all contiguous masses of metal—gutters, water-pipes, &c.—should be metallically connected with it, for although there is no danger of a properly arranged lightning-conductor throwing off *lateral sparks* to any semi-insulated metallic masses near it, the discharge may in its course *divide* between the rod and other metallic bodies in its neighbourhood in good connection with the earth. The action of the conductor is purely passive; it offers to the disruptive discharge a line of small resistance, whereby those irresistible mechanical effects which attend the passage of the discharge through resisting matter are prevented.

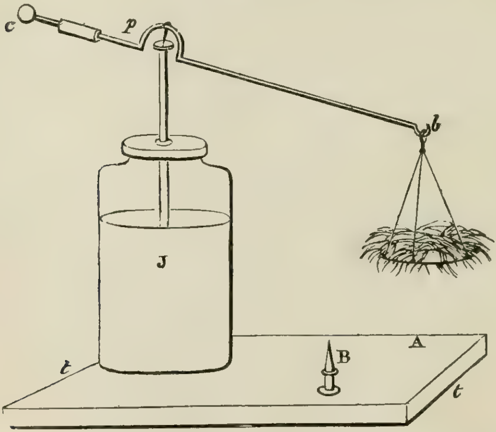
When large ranges of straggling buildings are to be protected, two or more conductors should be applied, and the whole connected together by bands of metal. Harris recommends that the conductors should be constructed of copper pipe, from one to two

inches in diameter, and about one-fifth of an inch thick; it may be prepared in lengths of about ten feet, and united together at the time of fixing by screwing the lengths together upon short intermediate pieces.

When a very dense electrical explosion falls on a conductor, the rod sometimes becomes covered with a luminous glow, and a loud whizzing sound is at the same time heard. This luminous appearance is, however, of a perfectly harmless character, and provided the conductor be of sufficient capacity, it is unattended with any calorific effect; it appears to be a sort of glow discharge (20, *c.*) between the metal and the air, immediately in the points of contact, and may be classed with the phosphorescent flashes attendant on the aurora borealis, or with the streaming of ordinary electricity in the exhausted receiver of an air-pump.

The following experiment was arranged by Sir Wm. Harris (*Nature of Thunderstorms*), with the view of illustrating the power of pointed bodies to discharge the electricity of the clouds *without attracting them.* *c p b* (Fig. 64) is a long bent of arm of light brass wire, balanced by means of a central point, *p*, on the charging rod of the jar J, on which it has free motion in all directions; A is a light disc of gilded wood, resembling a common scale pan, covered

Fig. 64.



with a lock of fine cotton-wool, and suspended by conducting threads from the arm *c p b*. A pointed body, B, is placed on the same conducting base as the jar. If the jar be now charged, the cotton in the scale pan will begin to extend its filaments, and the whole will be attracted towards the table much in the same way as a cloud appears to be attracted towards the earth,

causing the bent arc $c\ p\ b$ to assume an inclined position. If the arm be now caused to move upon its centre, p, so as to allow the artificial cloud A to approach the point B, the arm will gradually assume its previous horizontal position, in consequence of the influence of the point in neutralising the opposite forces. As the artificial cloud continues to approach the point, this action proceeds so rapidly as frequently to produce a whizzing sound, the bent arm recovering at the same time its horizontal position. The scale-pan A, so far from being attracted by the point, actually recedes from it, and represents very faithfully the nature of the operation of pointed bodies on charged clouds.

Fig. 65.

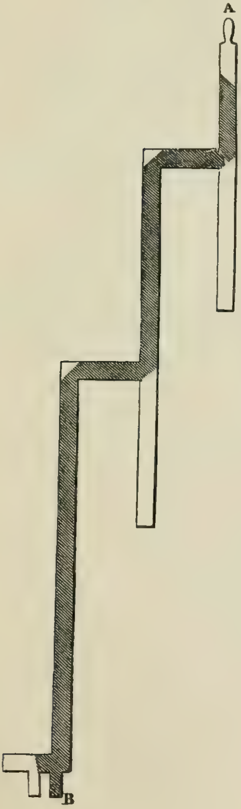
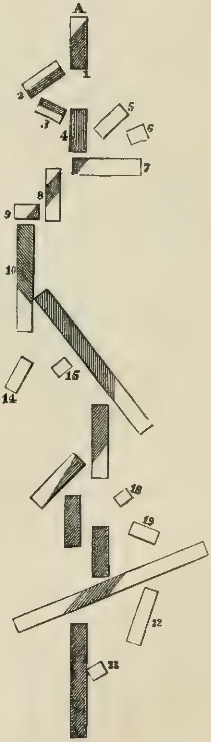


Fig. 66.



The following instructive experiments were also devised by Harris for the purpose of proving that an electrical explosion will not leave a good conductor, constituting an efficient line of action, to fall upon bodies out of that line:—

Lay some small pieces of gold leaf on a piece of paper, as represented in Fig. 65; pass a dense shock of electricity (from not less than eight square feet of coating) over these from the commencement at A to the termination at B, so as to destroy the gold; the line which the discharge has taken will be as shown in Fig. 66, which is copied from the actual effects of an electrical discharge. By the result of the explosion represented in Fig. 66, it is shown that the portions of the conductor below the striking parts are out of the line of discharge, and not involved in the result.

In Fig. 66 it is particularly worthy of remark that not only are the pieces 5, 6, 14, 15, 18, 19, 22, 23, untouched, being from their positions of no use in facilitating the progress of the discharge, but even portions of other pieces which have so operated are left uninjured, as 2, 3, 8, 9, 10, so little is there any tendency to a lateral discharge, even up to the point of dispersion of the metallic circuit in which the charge has proceeded. Indeed, as Harris observes, so completely is the effect confined to the line of least resistance, that percussion powder may be placed with impunity in the interval between the portions 4 and 5, and the separated pieces of gold leaf thus placed may be taken to represent detached conducting masses fortuitously placed along the mast and hull of a ship, and that therefore any fear that a conductor on a ship's mast would operate on the magazine is quite unwarranted.

(53) **Lightning Conductors for Ships.**—Formerly the conductors used for protecting ships against the effects of lightning consisted of chains or links of copper about the size of a goose quill, which were generally packed away in a box, where they frequently remained untouched during long and hazardous voyages. It was the late Mr. Singer who first suggested that fixed conductors should be employed, but the perfection of the *system*, and its general introduction into the navies and merchant services of nearly all countries, is due to the unceasing labours of Sir William Snow Harris.

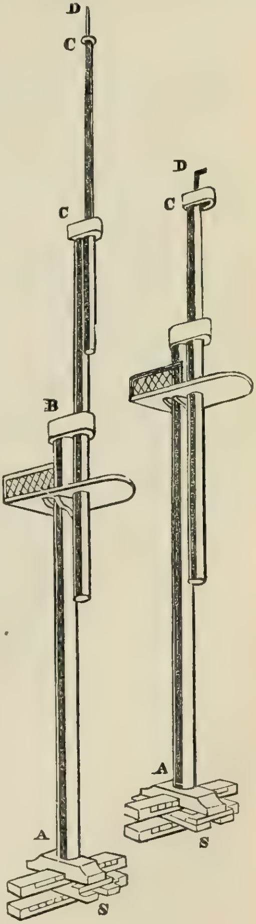
His original proposition (*Nautical Magazine*, 1852) was to incorporate with the masts a series of copper-plates from the truck to the keelson, so mechanically arranged and combined in two laminæ as to yield freely to any flexure or strain to which the spars might be subject, at the same time preserving an efficient and unbroken chain, and then to connect these vertical conducting lines by conducting plates similarly arranged with the various metallic bolts passing through the keelson and other parts of the hull to the copper expanded over the bottom, thus uniting as it were into one great chain the conductor on the mast, the metallic bodies on the hull, and the general surface of the sea, so that from the moment of lightning falling on any point aloft the explosion

would cease, and the general fabric would be insured against damage.

Harris's improved system of lightning conductors for ships is shown in Figs. 67, 68.

A B C D is the conductor, consisting of a series of narrow plates of sheet copper in lengths of four feet, placed in two layers, one immediately over the other, in such a way as to allow the joints of one series to fall immediately under or over the continuous portions of the other. The plates are laid in shallow grooves cut for their reception along the *aft* sides of the respective masts, from the truck to the keelson, and preserving an adequate connection in the caps through which the upper portions of the mast are required to slide. The elongation or contraction of the masts, or the removal of either of them, in no way disturbs the continuity of the line, which evidently remains the same, and is the shortest and best conducting line between the mast-head at D and the sea at S.

Fig. 67. Fig. 68.



The security ensured to ships by this system of lightning conductors is demonstrated by the following analysis of recorded cases of 'Ships Struck by Lightning,' published by Harris in the *Nautical Magazine*, 1852:—

'The general system of lightning conductors has been more or less in use since the year 1830; at first in about ten of Her Majesty's ships, and since 1842 throughout the whole navy, which gives a clear course of experiments of at least twenty years. Now during this time the ships having the new conductors have been exposed to lightning in its most appalling forms in almost every part of the world; and during these twenty years there are not more than forty recorded cases of ships struck by lightning, though numbers of remarkable instances in which the conductors have carried off tranquilly, as it were, large streams of atmospheric electricity. *In no case has any ill consequence ensued.* Between 1822 and 1842—that is, up to the date at which the system was fully adopted,

and including ten years common to both periods—there are sixty recorded cases of ships struck, and in every instance destructive damage ensued, and in many cases to a frightful extent. It thus appears that ships *not* furnished with the new conductors have been struck by lightning more frequently than ships having such conductors in the proportions of three to two—a result quite conclusive of the question whether such conductors do or do not operate in attracting lightning to the ship. In short, since the general introduction of this system into the public service, damage from lightning has vanished altogether from the records of the navy.'

As an illustration of the tremendous explosive power of lightning when it strikes the unprotected mast of a ship, we may quote the case of H.M. ship 'Elephant,' which was struck by a powerful flash of lightning in November 1790.

The mast weighed 18 tons; it was 3 feet in diameter and 110 feet long, and was strongly bound together by iron hoops, some of which were half an inch thick and 5 inches wide; yet it was shivered into pieces, and the hoops were burst open and scattered around amidst the shattered fragments of the mast.—(*Harris.*)

An instructive illustration of the protective power of a conductor is afforded by the instance of the 'Dido,' which was struck by a bifurcated flash of lightning which fell upon the main royal mast in May 1847.

One of the branches struck the extreme point of the royal yard arm, *which was not supplied with a conductor*, and in its course to the conductor on the mast demolished the yard, and tore in pieces or scorched up the greater part of the sail; the other part fell on the vane-spindle and truck, which last was split open on the instant that the discharge seized the conductor. From this point, however, the explosive action ceased, and the discharge freely traversed the whole line of the conductor, from the masthead (which was supplied with a conductor) downwards, without doing further damage.

(54) **Volcanic Eruptions in the Sea.**—These being generally attended by thunder and lightning, may be classed among electrical phenomena. In June 1811, Captain Tilland observed, off the island of St. Michael, one of these marine volcanoes, of which he has given the following account (*Phil. Trans.*):—

'Imagine an immense body of smoke rising from the sea. In a quiescent state it had the appearance of a circular cloud revolving in the water like a horizontal wheel, in various and irregular involutions, expanding itself gradually on the lee side; when suddenly a column of the blackest cinders, ashes, and stones would shoot up in the form of a spire, rapidly succeeded by others. each acquiring greater velocity, and breaking into various branches resembling a group of pines; these again forming themselves into festoons of white feathery smoke. During these bursts the most vivid flashes of lightning continually issued from the densest part of the volcano, and the columns rolled off in large masses of fleecy clouds, gradually expanding themselves before the wind, in a direction nearly horizontal, and drawing up a quantity of waterspouts. In less than an hour a peak was visible, and

in three hours from the time of our arrival, the volcano then being four hours old, a crater was formed twenty feet high and from four to five hundred feet in diameter.

'The eruptions were attended by a noise like the firing of a cannon and musketry mixed, as also with shocks of earthquake, sufficient to throw down a large part of the cliff on which we stood. I afterwards visited the volcanic island; it was eighty yards high; its crater upon the level of the sea was full of boiling water; it was about a *mile* in circumference, and composed of porous cinders and masses of stone.'

(55) **Tornadoes.**—It has been a subject of discussion whether tornadoes are really electrical phenomena, or whether they are caused by heat evolved from condensing vapour. From the following account of the devastating effects of one of these meteors which occurred at Châtenay, near Paris, in 1839, it appears that they are accompanied by marked electrical disturbances (*Report by Peltier to the French Academy of Sciences in* 1839):—

'Up to this time there had been thunder continually rumbling within the second thunder-cloud, when suddenly an under portion of this cloud descending and entering into communication with the earth the thunder ceased. A prodigious attractive force was exerted forthwith; all the dust and other light bodies which covered the surface of the earth mounted towards the apex of the cone formed by the cloud, and a rumbling thunder was continually heard. Small clouds wheeled about the inverted cone, rising and descending with rapidity. The column was terminated by a cap of fire. To the south-east of the tornado, on the side exposed to it, the trees were shattered, while those on the other side of it preserved their sap and verdure . . . . finally it advanced to the park and castle of Châtenay, overthrowing everything in its path. On entering the park, which is on the summit of a hill, it desolated one of the most agreeable residences in the neighbourhood of Paris. All the finest trees were uprooted, the youngest only, which were *without* the tornado, having escaped. The walls were thrown down, the roofs and chimneys of the castle and farm house carried away, and branches, tiles, and other movable bodies were thrown to a distance of more than five hundred yards. Descending the hill towards the north, the tornado stopped over a pond, killed the fish, overthrew the trees, withering their leaves, and then proceeded slowly along the avenue of willows, the roots of which entered the water; and being, during this part of its progress, much diminished in size and form, it proceeded slowly over a plain, and finally, at a distance of more than a thousand yards from Châtenay, divided into two parts, one of which disappeared in the clouds, the other in the ground. . . . Flashes, fiery balls, and sparks accompanied the tornado; a smell of sulphur remained for several days in the house, in which the curtains were found discoloured. . . . Everything,' observes Peltier, 'proves that the tornado is nothing else than a conductor formed of the clouds, which serves as a passage for a continual discharge of electricity from those above; and that the difference between an ordinary thunderstorm and one accompanied by a tornado consists in the presence of a conductor of clouds, which seem to maintain the combat between the upper portions of the tornado and the ground beneath.'

(56) **Waterspouts.**—Electrical agencies are supposed to be concerned in the production of waterspouts, which are at sea what whirlwinds are on land. These phenomena are considered to arise from the operation of electrical attraction. The following account of a waterspout which nearly overwhelmed the vessel is given by Captain Beechey, in his published account of his voyage in the Pacific, when he commanded the 'Blossom:'—

'It approached amidst heavy rain, thunder and lightning, and was not seen until it was very near the ship. The wind blew with great violence, momentarily changing its direction, as if it were sweeping round in short spirals; the rain, which fell in torrents, was also precipitated in curves, with short intervals of cessation. Amidst this shower the waterspout was discovered extending in a lapwing form from a dense stratum of cloud to within thirty feet of the water, where it was hid by the foam of the sea, being whirled upwards by a tremendous gyration. It changed its direction after it was first seen, and threatened to pass over the ship, but being diverted from its course by a heavy gust of wind it gradually receded. On the dispersion of this magnificent phenomenon, we observed the column to diminish gradually, and at length retire from the cloud from which it had descended, in an undulating form. . . . A *ball of fire* was observed to be precipitated into the sea, and there was much lightning. The column of the waterspout first descended in a spiral form, until it met the ascending column a short distance from the sea. A second and a third were afterwards formed, which subsequently united into one large column; and this again separated in three small spirals, and then dispersed. The barometer was not affected, but the thermometer fell eight degrees. The gyrations were in a direction contrary to that of the hands of a watch.'

The appearance of a waterspout, as seen by Captain Beechey, at the commencement of its formation, is shown in Fig. 69. The cone gradually elongated, and as its apex approached the sea the surface of the latter was perceptibly agitated, and became whirled in the air with a rapid gyration, forming a vast basin, from the centre of which the gradually lengthening column seemed to drink fresh supplies of water, as shown in Fig. 70. After a time heavy rain fell from the right of the arch at a short distance from the spout, upon which the waterspout began to retire. The sea, on the contrary, was more agitated, and for several minutes the basin continued to increase in size, although the column was considerably diminished. Its appearance at this time is shown in Fig. 71. In a few minutes more the column had entirely disappeared. The sea, however, still continued agitated, and did not subside for three minutes after all disturbing causes from above had vanished.

(57) **The Aurora Borealis.**—Although no theory that has yet been suggested to account for this magnificent meteorological phenomenon has received general acceptation, it is evident that

Fig. 69.

Fig. 70.

Fig. 71.

the agent to which its development is due is electricity, influenced in some as yet unascertained manner by terrestrial magnetism.

The appearance of an aurora may be closely imitated by passing a stream of electricity from the prime conductor of an electrical machine through a tube exhausted of air—the same variety of colour and intensity, the same undulating motions and occasional coruscations, and the same inequality in the luminous appearance are exhibited as in the aurora, and when the rarefaction is considerable, various parts of the stream assume that peculiar glowing colour which occasionally appears in the atmosphere.

This beautiful experiment is thus modified by De la Rive (*Comptes Rendus*, Oct. 15, 1849).

A cylindrical rod of iron is cemented air-tight into a glass globe. It is covered, except at its two ends, with an insulating and thick layer of wax. A copper ring surrounds the bar above the insulating layer in its internal part, the nearest to the side of the globe; from this ring proceeds a conducting rod, which, carefully insulated, traverses the same tubulure as the iron bar, but without communicating with it, and terminates externally in a knob or hook. The air being rarefied through a stop-cock attached to a second tubulure, the hook or knob is made to communicate with one conductor, and the external extremity of the bar with the other conductor of an electrical machine; the electricities unite in the globe, forming a more or less regular fascicle of light. On bringing the external end of the iron bar into contact with a pole of an electro-magnet, taking care to preserve good insulation, the light becomes a luminous ring, which *rotates round the bar* in a direction regulated by the magnetisation of the bar. From this luminous ring brilliant jets issue and form the fascicle. On removing the electro-magnet these phenomena cease, giving place to the previous appearance, and what is generally known by the name of '*the electrical egg*'

The following is a general description of the aurora as observed by M. Lottin, at Bossekop, in the Bay of Alten, on the coast of West Finland, in lat. 70° N., during the winter of 1838–9 (*Becquerel's Traité de Météorologie*) :—

'Between the hours of four and six in the afternoon, the sea-fog, which constantly prevails in those regions, becomes coloured on its upper border, or rather is fringed, with the light of the aurora, which is behind it. This border becomes gradually more regular, and takes the form of an arc, of a pale yellow colour, the edges of which are diffuse, and the extremities resting on the horizon. The bow swells upwards more or less slowly, its summit being constantly on the magnetic meridian, or very nearly so. The luminous matter of the arc soon becomes divided regularly by blackish streaks, and is resolved into a system of rays. These rays are alternately extended and contracted, sometimes slowly, sometimes instantaneously; sometimes they would dart out, increasing and diminishing suddenly in splendour. The inferior parts of the feet of the rays present always the most vivid light, and form an arc of greater or less regularity. The length of these rays was often very varied, but they all converged to that point of the heavens

indicated by the direction of the *south* pole of the dipping needle. Sometimes they were prolonged to the point, where their directions intersected, and formed the summit of an enormous dome of light. The bow would then continue to ascend towards the zenith. Its light would experience an undulatory movement; that is, from one extremity to the other the brightness of the rays would increase successively in intensity. This luminous current would appear several times in quick succession, and it would pass much more frequently from west to east than in the opposite direction. Sometimes, though rarely, a retrograde motion would take place immediately afterwards; and as soon as this wave of light had run successively over all the rays of the aurora from west to east, it would return in the contrary direction to the point of its departure. The bow thus presenting the appearance of an alternate motion in a direction nearly horizontal, had usually the appearance of the undulations or folds of a riband, or of a flag agitated by the wind. Sometimes one, sometimes both of its extremities would desert the horizon, and then its fold would become more numerous and marked; the bow would change its character and assume the form of a long sheet of rays returning into itself, and consisting of several parts, forming graceful curves. The brightness of the rays would vary suddenly, sometimes surpassing in splendour stars of the first magnitude. These rays would rapidly dart out, and curves would be formed and developed like the folds of a serpent; then the rays would assume various colours: the base would be blood red, the middle pale emerald green, and the remainder would preserve its clear yellow hue. These colours always retained their respective positions, and they were of admirable transparency; the brightness would then diminish, the colour disappear, and all would be extinguished—sometimes suddenly, sometimes gradually.

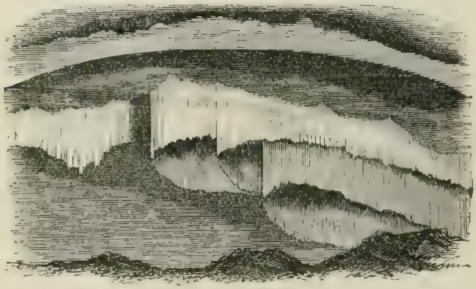
'After this disappearance, fragments of the bow would be reproduced, and would continue their upward movement and approach the zenith. The rays, by the effect of perspective, would be gradually shortened; the thickness of the arc, which presented thus the appearance of a larger zone of parallel rays, could be estimated; then the vortex of the bow would reach the magnetic zenith, or the point to which the south pole of the dipping needle is directed. At that moment the rays would be seen in the direction of their feet. If they were coloured, they would appear as a large red band, through which the green tints of their superior darts could be distinguished; and if the wave of light above mentioned pass along them, their feet would form a long, sinuous, undulating zone; while throughout all these changes the rays would never suffer any oscillation in the direction of their axis, and would constantly preserve their mutual parallelisms. In the meantime new arcs are formed, either commencing in the same diffuse manner, or with perfectly formed and very vivid rays. They succeed each other, passing through nearly the same phases, and arrange themselves at certain distances from each other. As many as nine have been counted, forming as many bows, having their ends supported on the earth, and in their arrangement resembling the short curtains suspended one behind the other over the scene of a theatre, and intended to represent the sky. Sometimes the intervals between these bows diminish, and two or more of them close upon each other, forming one large zone, traversing the heavens, and disappearing towards the south, becoming rapidly feeble after passing our zenith. If we can picture to our imagination all these vivid rays of light issuing forth

with splendour, and varying continually and suddenly in their length and brightness, coloured at intervals with beautiful red and green tints, with waves of light undulating over them, the whole firmament presenting one

Fig. 72.

immense and magnificent dome of light reposing on the snow-covered base supplied by the ground, which itself serves as a dazzling frame for a sea calm and black as a pitchy lake, some idea may be obtained of the splendid

Fig. 73.



spectacle which is presented to him who witnesses for the first time the aurora in the Bay of Alten.'

Figs. 72, 73, 74, 75 may serve as representations of some of the phenomena above described. They are copied from engravings in M. Lottin's Memoir.

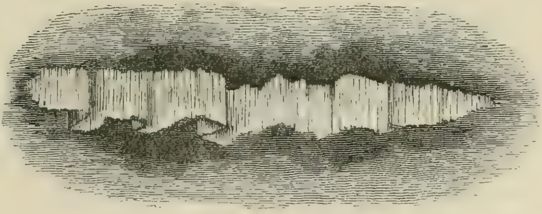
During the winter of 1838–9, between September 1838 and April 1839, M. Lottin observed no less than 143 auroras in the Bay of Alten. They were most frequent during the period while the sun remained below the horizon—that is, from the 17th of November to the 25th of January. During these nights he observed 70

auroras, without counting those which were rendered nearly invisible by a clouded sky, the presence of which was indicated by the disturbance of the magnetic needle.

Fig. 74.

It is very rarely that an aurora is observed complete in any but the northern regions. Sometimes the bow is either incomplete in itself, or is divided into several points; at other times the light is intercepted by clouds, which modify both the colour and the depth

Fig. 75.



of the borders. Many other circumstances concur in interfering in various ways with its regular formation.

The aurora borealis is seldom seen in perfection in this country. In October 1792, Dr. Dalton witnessed one which he watched with great attention, and of which he has furnished the following account (*Meteorological Essays*) :—

'Attention was first excited by a remarkably red appearance of the clouds to the south, which afforded sufficient light to read by at eight o'clock in the evening, though there was no moon or light in the north. From half-past nine to ten there was a large luminous horizontal arch to the southward, and several faint concentric arches northward. It was particularly noticed that all the arches seemed exactly bisected by the plane of the

magnetic meridian. At half-past ten o'clock streamers appeared, very low in the south-east, running to and fro from west to east; they increased in number, and began to approach the zenith apparently with an accelerated velocity, when all on a sudden the whole hemisphere was covered with them, and exhibited such an appearance as passes all description. The intensity of the light, the prodigious number and volatility of the beams, the grand admixture of all the prismatic colours in their utmost splendour, variegating the glowing canopy with the most luxuriant and enchanting scenery, afforded an awful, but at the same time the most pleasing and sublime, spectacle in nature. Every one gazed with astonishment, but the uncommon grandeur of the scene only lasted *one minute*; the variety of colours disappeared, and the beams lost their lateral motion and were converted into the flashing radiations. Notwithstanding the suddenness of the effulgence at the breaking out of the aurora, there was a remarkable regularity in the manner. Apparently a ball of fire ran along from east to west, with a velocity so great as to be barely distinguishable from one continued train, which kindled up the several rows of beams one after another. These rows were situated before each other with the exactest order, so that the base of each row formed a circle, crossing the magnetic meridian at right angles; and the several circles rose one above another, so that those near the zenith appeared more distant from each other than those near the horizon—a certain indication that the real distances of the rows were nearly the same. The aurora continued for several hours. There were many meteors (falling stars, as they are commonly called) seen at the same time; but they appeared to be below, and unconnected with the aurora.'

Whether the 'magnetic storms' manifested by auroral display share with electric storms the phenomena of sound as well as of light, appears doubtful. Nairne, Cavallo, and Hearne at the mouth of the Copper Mine River, and Henderson, in Iceland, each heard 'hissing sounds,' which they regarded as connected with the aurora, but which Wentzel attributed to the contracting of the snow from the sudden increase of cold. Parry, Franklin, and Richardson, who have seen thousands of auroras in different parts of the world, never heard any noise. The *height* of the aurora is likewise an uncertain point, the results of different measurements giving heights varying from a few thousand feet to several miles. The most modern observers seem, however, disposed to place the seat of the phenomena not at the limits of the atmosphere but in the region of the clouds, and they even believe that the rays of the aurora may be moved to and fro by winds and currents of air.

Faraday has thrown out the idea that aurora may be connected with currents of electricity induced by the earth's rotation. He says (*Ex. Research.* p. 192):—

'I hardly dare venture, even in the most hypothetical form, to ask whether the aurora borealis and australis may not be the discharge of electricity thus urged towards the poles of the earth, from whence it is endeavouring to return by natural and appointed means above the earth to the

equatorial regions. The non-occurrence of it in very high latitudes is not at all against this supposition; and it is remarkable that Mr. Fox, who observed the deflections of the magnetic needle at Falmouth, by the aurora borealis, gives that description of it which perfectly agrees with the present view. He states that all the variations at night were towards the east; and this is what would happen if electric currents were setting from south to north in the earth under the needle, or from north to south in spheres above it.'

(58) **De la Rive's Theory of the Aurora.**—(*Phil. Mag.*, vol. xxxiv. p. 286). It is founded on the following considerations:—Atmospheric electricity has its origin in the unequal distribution of temperature in the strata of the atmosphere; *positive* electricity proceeds from the *hot* part of a body to the *cold*, *negative* electricity moves in the contrary direction; hence the lower column of the atmosphere is constantly negative, and the upper column positive. The difference is more marked in our latitudes in summer than in winter, and more striking in general in the equatorial than in the polar regions. The negative state of the lower column is communicated to the earth on which it rests, and thus positive electricity increases with the height of the atmosphere.

The opposite electrical states of the upper and lower regions of the air undergo neutralisation when the tension reaches a certain degree of energy, by humidity, rain, snow, &c. De la Rive conceives that at the polar regions the positive electricity of the atmosphere combines readily with the negative there accumulated on the earth, because of the great humidity of the air in those regions a *current is thus formed*; for the electricity returns by the surface of the earth from the poles to the lower portion of the stratum, from whence it started. The current is from south to north in the upper regions of the atmosphere, and from north to south on the surface of the earth. The same takes place in both hemispheres; consequently for an observer, travelling from north to south, the current would proceed in the same direction from the north pole to the equator, and in a contrary direction from the equator to the pole.

The aurora borealis M. de la Rive considers to be the luminous effects of these currents travelling in these high regions towards the north pole, and thus explains the phenomena. When the sun, having passed into the southern hemisphere, no longer heats so much *our* atmosphere, a condensation of moisture, in the form of ice or snow, takes place around the polar regions, and electricity is hereby conducted to the surface of the earth in the form of electric discharges. When clouds are partial, *halos* are formed. The identity (he observes) between the light of the aurora and electric light is proved by well-known experiments. The light produced

by the electric discharge is highly rarefied, but purely *dry* air is very faint; the luminous effect is, however, greatly increased when moisture is present.

The reason why these phenomena appear at the *magnetic* and not at the *terrestrial* pole, is illustrated experimentally by De la Rive in the following manner: —

Place the pole of a powerful electro-magnet underneath the surface of mercury, connected with the negative pole of a powerful galvanic battery, bring over and near it the positive pole armed with a charcoal point, a voltaic arc is formed, and the mercury is agitated above the magnet; *luminous currents rotate round the pole*, throwing out occasionally brilliant rays. There is always, as in the case of the aurora borealis, a dark portion in the form of a circular point over the pole of the magnet. With a continuous current of an ordinary electricity arriving at the pole of a powerful electro-magnet in moist rarefied air, luminous effects still more similar to those of the aurora borealis are obtained. These phenomena result from the action of magnets on currents, and the same should apply to the action of the magnetic pole of the earth.

(59) **The Aurora a Magnetic Phenomenon.**—Recent experiments have failed to show a connection between polar light and atmospheric electricity, since during the finest auroræ no change has been detected in very sensitive electrometers. On the other hand (observes Humboldt) all the three manifestations of terrestrial magnetism—the declination, the inclination, and force—are affected in a very sensible manner, the same end of the needle being sometimes attracted and sometimes repelled in the course of the same night.

The luminous phenomenon is regarded by Humboldt as the restoration of the equilibrium temporarily disturbed; the termination of a magnetic storm and the effect of the needle varies with the intensity of the discharge. The aurora is not to be regarded as the cause of the magnetic perturbation, but as the result of a state of '*electric activity*' excited to the production of a luminous phenomenon; an activity which manifests itself on the one hand by the fluctuations of the needle, and on the other by the appearance of a brilliant auroral light.

A great difference between an *electrical* and a *magnetic* storm is, that the former is usually confined to a small space, beyond which the state of the electricity in the atmosphere remains unchanged; the latter, on the other hand, manifests its influence on the march of the needle over large portions of continents, and far from the place where the evolution of light is visible. 'That the aurora,' says Humboldt, 'is a magnetic phenomenon has, by Faraday's brilliant discovery of the evolution of light by the action of magnetic forces, been raised from a mere conjecture to an experimental certainty. The fact which gives to the phenomenon its

greatest importance is that the earth becomes *self-luminous*; that besides the light which as a planet it receives from the central body, it shows a capability of sustaining a luminous process proper to itself, and this, going on almost uninterruptedly in the polar regions, leads us by analogy to the remarkable phenomenon presented by Venus when the portion of that planet not illuminated by the sun is seen to shine with a phosphorescent light of its own.'

(60) **Action of Atmospheric Electricity on the Wires of the Electric Telegraph.**—According to the observations of Professor Henry, of Philadelphia (*Phil. Mag.*, vol. xxx. p. 186), the wires of the telegraph are struck by a direct discharge of lightning, which is seen coursing along the wire in a stream of light, sometimes passing with explosions resembling the reports of rifles down the poles in succession. These *lateral* explosions are referred to the charge of the surface of the wire, by a wave of the fluid, during the transmission of the electricity, which tends to give off sparks to neighbouring bodies like the conductor of a machine. The discharge from the clouds does not generally consist of a simple wave of electricity, but of a number of discharges in rapid succession along the same path, whence the wire of a telegraph is capable of transmitting an immense quantity of the fluid thus distributed over a great length of the conductor. Henry thinks that when the discharge takes place, a disturbance of the electrical *plenum* existing throughout all electrical space occurs, the state of rest being attained by a series of diminishing oscillations or waves, which by their reflections enhance the tendency of the fluid to fly from the conductor.

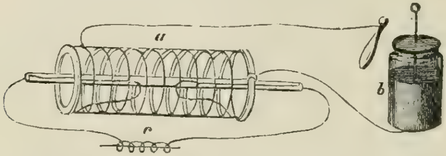
The natural state of the telegraph wire may be disturbed without the presence of a thunder-cloud, by the passage of currents of electricity from one portion of space to another, the electrical condition of the atmosphere surrounding the wire at one place being different from that at another. A difference of elevation will do this, as kite experiments abundantly testify, so that if the line of telegraph pass over an elevated mountain ridge, there will be continually, even during clear weather, a current from the more elevated to the lower points of the conductor. Vapour, fog, snow, or rain at one end of the wire, and not at the other, may likewise determine currents of electricity of sufficient power to set the working machine of the telegraph in action. The natural electricity of the telegraph wire may even be disturbed by the induction of a distant cloud moving first towards and then from the wire, though such currents would be feeble.

A fruitful source of disturbance of the needle is the powerful currents produced by *induction* by flashes of lightning occurring

perhaps many miles off. That discharges from electricity accumulated in the Leyden jar are competent to induce secondary and even tertiary and quaternary currents in vicinal conductors, is demonstrated by the following experiment, first made by Professor Henry.

Round a hollow glass cylinder, *a* (Fig. 76), of about six inches in diameter, is pasted spirally a narrow ribbon of tin foil about thirty feet long, and a similar ribbon of the same length is pasted on the inside, so that the corresponding spires of each are directly opposite each other. The ends of the inner spiral pass out of the cylinder through a glass tube, in order to prevent all direct communication between the two. When the ends of the

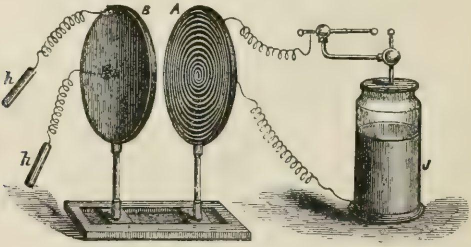
Fig. 76.



inner ribbon are joined by the magnetising spiral *c*, containing a needle, and a discharge from a half-gallon jar is sent through the outer ribbon, the needle is strongly magnetised in such a manner as to indicate an induced current through the inner ribbon *in the same direction* as that of the current of the jar. If a second cylinder, similarly prepared, be added, a *tertiary* current is induced in the inner ribbon of the second; and by the addition of a third cylinder, a current of the *fourth* order may be developed.

Another instructive method of demonstrating the development of secondary or induction currents by the discharge of a Leyden jar or battery, is the following, which is the arrangement of Matteucci:—

Fig. 77.



A and B (Fig. 77) are discs of glass or gutta-percha fixed vertically in metallic frames, and supported on insulated stands. They are about a foot in diameter. On one face of each is wound spirally, commencing from the centre, a long and well-insulated copper wire, about one-tenth of an inch in

diameter; the ends of the wire pass through the disc at the centre, and near to the circumference, and are there terminated by binding screws. A is brought into the circuit of the jar or battery through a Lane's discharger, and the wired face of B brought close to it: every time the jar discharges, a shock of greater or less intensity, according to the interval between the discs, is experienced by a person grasping the handles *h h*. The spirals should be laid symmetrically on the discs, and the wire, after being well covered with silk, should be thickly covered with gum lac.

Henry sent sparks from an electrical machine through a parallelogram of about sixty feet by thirty of copper wire, suspended by silk strings round the ceiling of a room; a current was induced in a second similar parallelogram placed immediately below the first in a cellar of the building, *through two floors, and thirty feet distant*, sufficiently powerful to magnetise needles.

That similar effects may be produced by atmospheric electricity, was proved by soldering a wire to the metallic roof of the house and passing the other end down into a well. At every flash of lightning a series of currents in alternate directions was produced in the wire. Sparks have indeed been seen on the railroad itself, at the breaks of the continuity of the rail, with every flash of a distant thunder-cloud. Every discharge in the heavens must therefore produce inductive effects to a greater or less degree in the telegraph wires. In the Telegraph Office at Philadelphia, Henry observed sparks passing from the wire to a metallic surface in connection with the earth through nearly an inch, during the raging of a storm at Washington; such, indeed, was the quantity and intensity of the current, that the needle of an ordinary vertical galvanometer with a short wire, and not by any means sensible, was moved by it several degrees; its pungency was also very great. It is well known that small birds have sometimes been found hanging by their claws dead from the wire, having probably been killed by one of these inductive discharges.

'More damage,' observes Mr. Highton (*The Electric Telegraph*, p. 11), 'is often done to the telegraph in a single second by a single thunderstorm, than by all the mischievous acts of malicious persons in a whole year. Posts are split in pieces, coils of wire are fused, needles are demagnetised, and permanent magnetism given to soft iron electro-magnets.'

In the year 1846, the electric telegraph on the St. Germain's Railway was visited by an attack of atmospheric electricity, the following account of which was communicated by M. Breguet to M. Arago (*Year Book of Facts*, 1846):—

'About five o'clock in the afternoon, during a heavy fall of rain, the bells of the electric telegraph at Le Vesitret began to ring, which led the attendant to suppose that he was about to receive a communication. Several

letters then made their appearance, but finding they conveyed no meaning, he was about to make the signal "*Not understood*," when suddenly he heard an explosion similar to a loud pistol-shot, and at the same time a vivid flash of light was seen to run along the conductors placed against the sides of the shed. The conductors were broken into fragments, their edges being fused. The wires of several electro-magnets were also broken; and the attendant, who was holding the handle which moves the needle, sustained all over the body a violent concussion; several workmen standing about him also experienced severe shocks. At the other end of the line, at the Paris station, nothing was broken, and nothing remarkable occurred, excepting that several of the bells were heard to ring.'

At the Oundle Station of the London and North-Western Railway, considerable mischief was done in 1846, several of the coils being burst open, and the wires fused; and at the Chatham Station on the South-Eastern Railway, a flash of lightning destroyed, in August 1849, the wire of the bell-coil and both the galvanometer coils. In India, which is occasionally visited with storms of lightning such as we seldom witness in this country, the damage done is often much more severe; and in America the disastrous consequences resulting from the same cause soon after the establishment of the first line of telegraph by Morse, in 1844, rendered it imperatively necessary to devise some means for the protection of the wire.

According to the observations of M. Baumgartner (*Revue Scientifique*, Dec. 1849), the direction of the atmospheric electric currents along the telegraph wires is from Vienna to Sommering during the day, and inverse during the night, the change of direction taking place after the rising and setting of the sun. The regular current is less disturbed by irregular currents when the air is dry and the sky serene than when the weather is rainy, and the current is more intense with short than with long conductors. When the sky is cloudy and the weather stormy, currents are observed sufficiently intense to affect the telegraphic indicators, and the action is stronger on the approach of a storm.

Mr. Barlow has also made some curious observations on the direction of the disturbance of the telegraph needle. He found (*Phil. Mag.*, vol. xxxiv. p. 344) that in telegraphs proceeding northerly and north-easterly, i.e. from Derby N. towards Leeds, and from Derby NE. towards Lincoln, the direction of the disturbance was always contrary to those proceeding southerly and south-westerly, e.g. from Derby S. towards Rugby, and from Rugby SW. to Birmingham. He found currents at all times perceptible in telegraph wires between two earth conductors, but not so if the wires have no earth connection; that the changes ot force and direction were simultaneous at both ends of a wire forty

miles long, the current passing direct from one earth connection to the other; that there is a daily movement of the galvanometer needle, similar to that of the horizontal magnetic needle, produced by the electric currents travelling in one direction from 8 A.M. to 8 P.M., and returning in the opposite direction during the remainder of the twenty-four hours; the movement of the galvanometer needle being subject to disturbances which are the greatest during the prevalence of *auroræ*; that the direction in which these currents alternate is from NE. to SW., the effect not depending on the direction of the wire itself, but on the relative direction of the two earth connections.

Barlow made simultaneous observations with the galvanometer and a declinometer needle, from which it appeared that, taking the mean of many observations, that part of the day in which the current flows S. (i.e. from 8 or 9 A.M. till evening) the variation of the declinometer needle is W., and that during the night and early in the morning, at which time the currents travel N., the variation is E., also that those large disturbances called magnetic storms are simultaneous on both instruments. Barlow attributes these currents to thermo-electric action in the crust of the earth, while De la Rive considers them to originate in the atmosphere.

The extraordinary influence of the *aurora borealis* on the needle, and sometimes even on the bells of the electric telegraph, is thus noticed by Walker (*Electric Telegraph Manipulation*):—

'At such times needles move just as if a good working current were pursuing its ordinary course along the wires. They are deflected this way or that, at times with a quick motion, and changing rapidly from side to side many times in a few seconds; and at other times moving more slowly, and remaining deflected for many minutes, with greater or less intensity, their motions being inconstant and uncertain. These phenomena have occurred less frequently on the part of the line between Reigate and Dover, which runs nearly E. and W., than on the part between London and Reigate, which runs nearly N. and S. When, however, they do make their appearance on the telegraph in those parts, we are prepared to expect auroral manifestations when night arrives, and we are rarely disappointed. The deflections in their variations appear to coincide with the various phases of the aurora. On the branch line running from Ashford to Ramsgate, these deflections have been a much more common occurrence, even when the parts of the line were unaffected, and when no auroral phenomena were noticed. This branch nearly coincides with the curve of *equal dip*. A dipping needle inclines downward to the same angle at all places along this curve. Whether there is any relation between these two facts remains to be investigated. . . . The needles are also subject to feeble secular deflections corresponding with certain hours of the day. The wires also at times collect electricity from the atmosphere and affect the needles.'

In France two brilliant auroras occurred on the 29th of August and on the 1st of September 1859; both acted powerfully on the

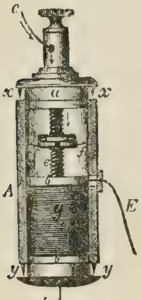
wires of the electric telegraph; the alarums were for a long time violently rung, and despatches were frequently interrupted by the spontaneous working of the apparatus.

(61) **Paratonnerres or Lightning Conductors for the Protection of Telegraph Lines.**—Various forms of conductor have been invented and adopted. Mr. Highton's plan, which he states to be very effectual, is very simple. The wire is surrounded for six or eight inches before it enters a telegraph instrument with bibulous or blotting paper, and passes through a deal box lined with tin plate in connection with the earth—the box is then filled with iron filings. When a flash of lightning happens to be intercepted by the wires of the telegraph, the myriads of infinitesimally fine points of metal in the filings surrounding the wire and having connection with the earth, at once draw off the whole charge of lightning and direct it to the earth, and thus the telegraph instrument will be protected from damage, even during the most fearful thunderstorms that may occur.

Mr. C. V. Walker's 'protector' consists of a small hollow metal cylinder connected with the earth. The line wire in its passage from the railway to the telegraph passes through this cylinder, traversing which it is first presented to the inner surface in the form of a thick wire furnished with spurs whose points are in the closest possible proximity to the cylinder without being in actual contact; it is then continued on and presented as a short coil of very fine wire wound on a bobbin, the outer convolution of the coil being very close to the cylinder.

This instrument is shown in Fig. 78. The line wire is attached at *c*, the instrument at *d*, and there is a complete metallic connection between these points to the screw *e*, and the very fine wire wound on *g*; A is a cylinder of brass, insulated from the line wire by boxwood, and in communication with the earth at E. The metal points at *f x y* allow the atmospheric electricity to escape to the outer cylinder, and so to the earth, while the very fine wire on *g* must be fused before the coarser wire in the instrument can suffer.

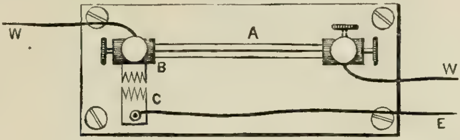
Fig. 78.



Breguet's paratonnerre, which is much used on the French telegraph lines, is shown in Fig. 79. The line wire is connected with a very fine iron wire placed in a glass tube, capped at both ends with brass and screwed on to a board. To the side of one of the brass caps is fastened a serrated piece of metal B, immediately opposite, and as close as possible, to which is a similar serrated piece of metal C, in communication with the earth by the wire E; so that if the wire of the line should become charged with atmospheric electricity, it may

discharge itself by these points to the earth ; and in the event of a flash of lightning striking the line wire, the thin wire A would be fused, and the telegraph instrument protected.

Fig. 79.



On the Brunswick State Telegraphs, the main wire, well protected by gutta-percha, is passed through pipes underground, and fastened to a copper plate in the telegraph-room. From this plate a small insulated wire is extended to the signalling instrument, and through the battery to a second copper plate in connection with the earth. The two copper plates are insulated from each other by pieces of ivory. The two thin wires, which are covered with silk, are twisted together, but separated near the telegraph apparatus, to the screws of which they are attached. The galvanic current passes through the main wire to the first plate, through the thin wire to the apparatus and electro-magnet, through this to the galvanic battery and the second plate, over this to a stronger insulated wire to the ground, making a perfect circuit. But a discharge of atmospheric electricity would pass between the two copper plates rather than through long thin wires, and the telegraphic apparatus is thus effectually protected.

Fig. 80.

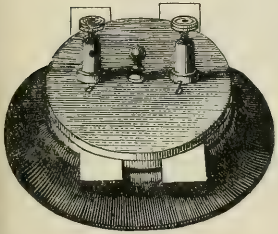
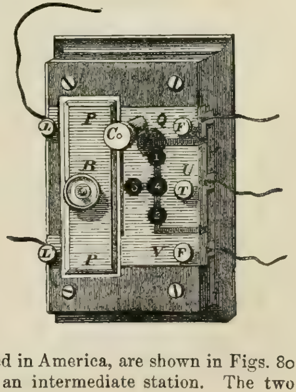


Fig. 81.



Other lightning protectors, much used in America, are shown in Figs. 80 and 81, the latter being intended for an intermediate station. The two

brass plates in Fig. 80 are about $2\frac{1}{2}$ inches in diameter, and $\frac{1}{16}$ inch thick; they are insulated from one another by strips of gutta-percha. The upper plate is in connection with the ine wire and the instrument by means of the two terminals *a b*. The lower plate is in communication with the earth. If lightning enters the station by the line wire, it leaps to the lower plate and passes to the earth, and the instruments are in safety. The instrument shown in Fig. 81 acts as a communicator as well as a lightning protector. By means of the metal plug *c*, and the holes 1 2 4, the line wire on either or both sides of the station can be put in connection with the earth, or a thorough passage can be opened to the current without its influencing the instrument at the station, by placing the plug at 3. This will be evident from the figure, the plate L Q F being in connection with the line wire entering one side of the station and one terminal of the instrument, and L′ V′ F′ being connected with the other side of the instrument, and the other line wire P B P, insulated from these plates by a strip of paper, is in connection with the earth; U also is connected with the earth.

(62) **What is Atmospheric Electricity?**—Is it electricity of the earth, or electricity of the air, or electricity of watery or other particles in the air?

Professor Thomson (*Proceedings of the Royal Institution*, May 18, 1860) does not agree with Peltier in regarding the earth as a resinously charged conductor insulated in space, and subject only to accidental influences from temporary electric deposits in clouds or air around it; because, although it is true that in severe weather the earth's surface is generally found to be negatively electrified, and although the earth is insulated in its atmospheric envelope, being in fact a conductor touched only by air (a strong insulator), it is to be remarked that air when highly rarefied becomes weak in its resistance to the transference of electricity through it, and begins to appear rather as a conductor than as an insulator, so that at a distance of one hundred miles or upwards from the earth's surface, the air in space cannot in all probability have resisting power enough to bear any such electric force, as those which we find even in serene weather in the lower strata, and there must always be *essentially* in the higher aërial regions a distribution arising from the self-relief by the outer highly rarefied air by disruptive discharges.

Thomson considers that this electric stratum must constitute very nearly the electropolar complement to all the electricity that exists on the earth's surface, and in the lower strata of the atmosphere.

The quality of non-resistance to electric force of the thin interplanetary air being considered, the *earth*, its *atmosphere*, and the surrounding medium may be regarded as constituting respectively the *inner* coating, the *dielectric*, and the outer coating of a large Leyden phial charged *negatively*.

The methods employed for collecting atmospheric electricity (burning match, dropping water), give the '*electric potential*' of the air at the point occupied by the burning match or by the portion of the stream of water where it breaks into drops. If the apparatus be used in an open plane, and if care be taken to eliminate all disturbing influences, the effect as indicated by the electrometer, if expressed in absolute electrostatic measure, and divided by the height of the point tested above the ground, has only to be divided by four times the ratio of the circumference to its diameter to reduce it to an expression of the number of units in absolute electrostatic measure of the electricity per unit of area of the earth's surface at the time and place.

The most convenient and intelligible way of stating the result of an observation of terrestrial atmospheric electricity in *absolute measure* is in the terms of a number of elements of a constant galvanic battery required to produce the same difference of potentials as exists between the earth and a point in the air at a stated height above an open level plane of ground.

Attempts have been made, hitherto without success, to determine whether the particles of rain, hail, and snow in falling through the air possess absolute charges of electricity; but Thomson thinks that by proper attention to insulation, and taking proper means to obviate the disturbing influences of induction, these interesting questions may be solved.

There can be no doubt that electric indications, when sufficiently studied, will be found important additions to our means for prognosticating the weather. Prior Ceca, in 1775, gave the following reply to a question put to him by Beccaria, concerning the state of electricity when the weather clears up:—

'If,' said the Prior, 'when the rain has ceased, strong *positive* electricity obtains, it is a sign that the weather will continue fair for several days; if the electricity is but small, it is a sign that such weather will not last so much as that whole day, and that it will soon be cloudy again, or even will again rain.'

This rule as to the 'electricity of clearing weather' has been found frequently confirmed by Professor Thomson, and he looks forward to an early period when the atmospheric electrometer will be as generally adopted as a useful and convenient weather-glass.

'In fair weather the surface of the earth is always, in these countries at all events, found negatively electrified. Now the limitation to these countries that I have made suggests a point for the practical telegraphists all over the world. Let us know whether it is only in England, France, and Italy that in fine weather the earth's surface is negatively electrified. The

only case of exception on record to this statement is Professor Piazzi Smyth's observations on the Peak of Teneriffe. There, during several months of perfectly fair weather, the surface of the mountain was, if the electric test applied was correct, positively electrified ; but Professor Piazzi Smyth has, I believe, pointed out that the observations must not be relied upon. The instrument, as he himself found, was not satisfactory. The science of observing the atmospheric electricity was then so much in its infancy that, though he went prepared with the best instrument, and the only existing rules for using it, there was a fatal doubt as to whether the electricity was positive or negative after all. But the fact that there has been such a doubt is important.

'Now I suppose there will be a telegraph to Teneriffe before long, and then I hope and trust some of the operators will find time to climb the Peak. I am sure that, even without an electric object, they will go up the Peak. Now they must go up the Peak with an electrometer in fine weather, and ascertain whether the surface of the earth is there positively or negatively electrified. If they find that on one fine day it is negatively electrified, the result will be valuable to science ; and if on several days it is found to be all day and all night negatively electrified, then there will be a very great accession to our knowledge regarding atmospheric electricity.

'When I say the surface of the earth is negatively electrified, I make a statement which I believe was due originally to Peltier. The more common form of statement is that the air is positively electrified, but this form of statement is apt to be delusive. More than that, it is most delusive in many published treatises, both in books and encyclopædia, upon the subject. I have in my mind one encyclopædia in which, in the article " Air, electricity of," it is said that the electricity of the air is positive, and increases in rising from the ground. In the same encyclopædia, in the article " Electricity, atmospheric," it is stated that the surface of the earth is negatively electrified, and that the air in contact with the earth, and for some height above the earth, is, in general, negatively electrified. I do not say too much, then, when I say that the statement that the air is positively electrified has been at all events a subject for ambiguous and contradictory propositions ; in fact, what we know by direct observation is, that the surface of the earth is negatively electrified, and positive electrification of the air is merely inferential. Suppose for a moment that there were no electricity whatever in the air—that the air was absolutely devoid of all electric manifestation, and that a charge of electricity were given to the whole earth. For this no great amount would be necessary. Such amounts as we deal with in our great submarine cables would, if given to the earth as a whole, produce a very considerable electrification of its whole surface. Well now, if all space were non-conducting—and experiments on vacuum tubes seem rather to support the possibility of that being the correct view—if all space were non-conducting, our atmosphere being a non-conductor, and the rarer and rarer air above us being a non-conductor, and the so-called vacuous space, or the interplanetary space beyond that (which we cannot admit to be really vacuous), being a non-conductor also, then a charge could be given to the earth as a whole, if there were the other body to come and go away again, just as a charge could be given to a pith-ball electrified in the air of this room. Then, I say, all the phenomena brought to light by atmo-

spheric electrometers, which we observe on a fine day, would be observed just as they are. The ordinary observation of atmospheric electricity would give just the result that we obtain from it. The result that we obtain every day of fair weather in ordinary observations on atmospheric electricity is precisely the same as if the earth were electrified negatively and the air had no electricity in it whatever.

'I have asserted strongly that the lower regions of the air are negatively electrified. On what foundation is this assertion made? Simply by observation. It is a matter of fact; it is not a matter of speculation. I find that the air which is drawn into a room from the outside on a fine day is negatively electrified. I believe the same phenomena will be observed in this city as in the old buildings of the University of Glasgow, in the middle of a very densely-peopled and smoky part of Glasgow; and therefore I doubt not that when air is drawn into this room from the outside, and a water-dropping collector is placed in the centre of the room, or a few feet above the floor, and put in connection with a sufficiently delicate electrometer, it will indicate negative electrification. Take an electric machine; place a spirit-lamp on its prime conductor; turn the machine for a time; take an umbrella, and agitate the air with it till the whole is well mixed up; and keep turning the machine, with the spirit-lamp burning on its prime conductor. Then apply your electric test, and you will find the air positively electrified. Again—let two rooms, with a door and passage between them, be used for the experiment. First shut the door and open the window in your observing room. Then, whatever electric operations you may have been performing, after a short time you find indications of negative electrification of the air. During all that time let us suppose that an electric machine has been turned in the neighbouring room, and a spirit-lamp burning on its prime conductor. Keep turning the electric machine in the neighbouring room, with the spirit-lamp as before. Make no other difference but this—shut the window and open the door. I am supposing that there is a fire in your experimenting room. When the window was open and the door closed, the fire drew its air from the window, and you got the air direct from without. Now shut the window and open the door into the next room, and gradually the electric manifestation changes. And here somebody may suggest that it is changed because of the opening of the door, and the inductive effect from the passage. But I anticipate that criticism by saying that my observation has told me that the change takes place gradually. For a time after the door is opened and the window closed, the electrification of the air in your experimental room continues negative, but it gradually becomes zero, and a little later becomes positive. It remains positive as long as you keep turning the electric machine in the other room and the door is open. If you stop turning the electric machine, then, after a considerable time, the manifestation changes once more to negative; or if you shut the door and open the window the manifestation changes more rapidly to negative. It is, then, proved beyond all doubt that the electricity which comes in at the windows of an ordinary room in town is ordinarily negative in fair weather. It is not always negative, however. I have found it positive on some days. In broken weather, rainy weather, and so on, it is sometimes positive and sometimes negative.'—*Sir William Thomson.*

CHAPTER VI.

MAGNETISM.

Natural and Artificial Magnets—General Principles of Magnetic Action—Magnetic Batteries—Laws of Magnetic Force—Terrestrial Magnetism—The Land and Mariner's Compass—The Inclination and the Declniation Magnet—The Variation of the Magnetic Needle—Terrestrial Magnetic Intensity—Magnetic Storms.

(63) **The Native Magnet or Natural Loadstone.**—This is an ore of iron consisting chiefly of the two oxides of that metal, with a small proportion of quartz and alumina. It is found in considerable masses in the iron mines of Sweden and Norway, and has been met with occasionally in the iron mines of England.

If we immerse a loadstone, no matter of what shape, in a quantity of clean iron filings, the filings will be observed to accumulate on two points exactly opposite each other, assuming the form shown in Fig. 82; these points are called the poles of the loadstone. If we balance a small needle of iron on a pivot, and bring it near either of these poles, we shall find that it will be attracted to it; or conversely, we may suspend the loadstone by a fine fibre, and bring into the vicinity of its poles a piece of soft iron, the loadstone will be attracted towards the iron.

Fig. 82.

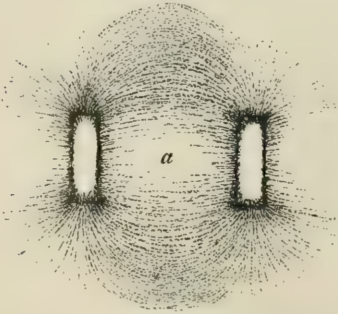
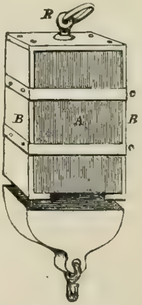


Fig. 83.



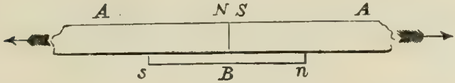
The power of the native magnet is greatly increased by adapting two pieces of flat soft iron to its poles, and enclosing it in a silver

or brass case, as shown in Fig. 83, where A is the loadstone; B B the two pieces of soft iron, the lower ends turning inwards; *c c* bars of copper to fasten the loadstone in its case, and R a ring inserted in the top of the box for the purpose of suspension.

(64) **The Artificial Magnet.**—If a small bar of well-hardened steel be drawn a few times across the poles of an armed loadstone, taking care not to remove the bar from either extremity of the latter, and to terminate the operation when its extremities are equidistant from either pole, it will be found to have acquired magnetic properties. For magnetising larger bars, a great number of processes have been invented.

1. *Knight's Method.*—The bar *s n* (Fig. 84) is placed under the poles N S of two equal magnets; the latter are he separated and moved slowly in

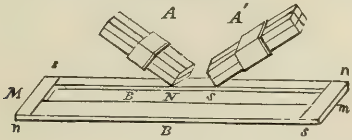
Fig. 84.



opposite directions S A, N A; this operation is repeated several times, when the bar will have acquired all the magnetism it is capable of receiving. Scoresby placed the bar to be magnetised *above* the magnets, repeating the process about six times on each side of the bar.

2. *Duhamel's Method.*—The bars to be magnetised are placed parallel to each other, and their extremities united by two pieces, M *m*, of soft iron

Fig. 85.

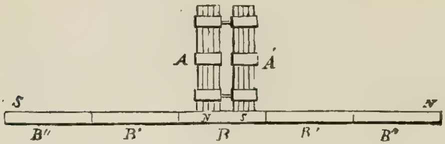


(Fig. 85). The inducing magnets A A′, which are either strong single bars, or bundles of smaller magnets, are placed, as in the figure, on one of the bars to be magnetised; they are then separated from each other as in Knight's method; the same is repeated on the other bar, and continued alternately on both till the magnetism is supposed to be completely developed on both bars. When the second bar is being operated upon, the disposition of the poles of the inducing magnets must of course be reversed.

3. *Mitchell's Method.*—This is called the *method of double touch.* Four or five equal steel bars are placed in the same straight line; two bundles of

magnets A A′ (Fig. 86) are joined together at a distance of one-fourth of an inch, their opposite poles being together; the double bundle is then placed upon the middle of the centre bar B, and moved backwards and forwards throughout the entire length of the line of bars, repeating the operation on each

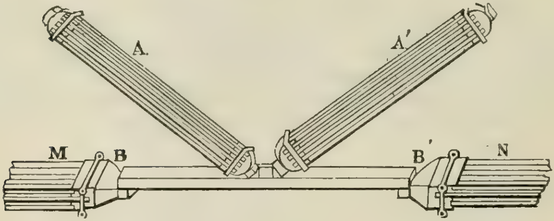
Fig. 86.



side till the greatest possible effect is produced. A powerful horseshoe magnet may be substituted for the double bundle of straight magnets in this process.

4. *Coulomb's Method.*—Fixed and moving bundles of magnets are employed. The bar to be magnetised is laid between the two fixed bundles M N (Fig. 87), with its ends resting on two projecting pieces of iron. The

Fig. 87.

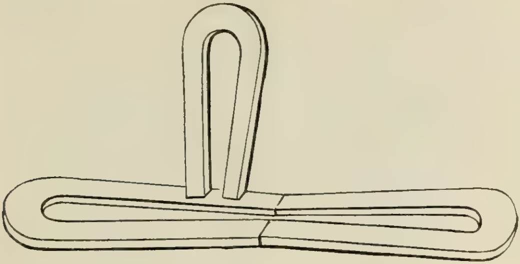


two bundles of inducing magnets A A′ are placed in the centre of the bar at an angle of 20° or 30°, their opposite poles being separated by a small piece of wood or copper one-fifth of an inch wide. They are then moved successively from the centre to each extremity of the bar B B several times, taking care to finish the operation when the united poles are in the centre of the bar. The same operation is repeated on the other side.

5. *Epinus's Method.*—If the bars to be magnetised have a horseshoe form, which is very convenient when both poles are required to act together, they are laid together as in Fig. 88, the ends which are intended to be contrary-poles being placed in contact; a powerful horseshoe magnet is then placed with its north pole next to that which is to be the south pole of one of the horseshoe bars, and then carried round and round, but always in the same direction. The bars are then turned over, and the process repeated, till a high degree of power has been imparted to them. Several precisely

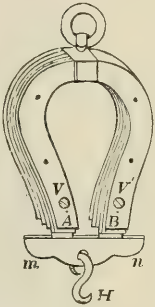
similar bars, when thus magnetised, may be united together by screws v v′ (Fig. 89), and thus constitute a powerful magnetic battery.

Fig. 88.



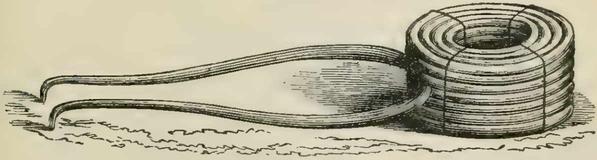
6. *By the Voltaic Current.*—About 25 feet of well-insulated copper wire are wound so as to form a hollow, very short, but thick cylinder (Fig. 90). A current from a strong Voltaic pair is passed through the wire, and the steel bar to be magnetised is placed in the cylinder, in which it is moved up and down to the very ends. When the central portion of the steel bar again occupies the cylinder, the circuit is opened and the bar, which is now perfectly magnetised, is withdrawn.

Fig. 89.



When the bar is curved in the form of a horseshoe, it is well to close it with its keeper during magnetising; and when a straight one, to provide it at the top and bottom with a piece of iron. By this process, which was first published by M. P. Elias, of Haarlem (*Phil. Mag.*, vol. xxv.), very large bars may be magnetised to saturation by a single passage through the cylinder.

Fig. 90.

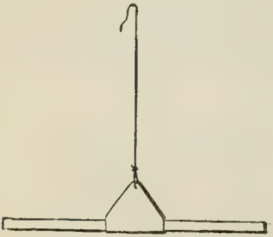


Magnets, when laid aside, should be placed in the position which they would assume, in consequence of the action of terrestrial

magnetism. All rough and violent treatment should be avoided, every concussion or vibration amongst its particles tending to weaken its power. The similar poles of two bar magnets should not be brought into contact, or both may be much weakened; they should be kept in pairs, with their dissimilar poles either in contact or connected together by two pieces of soft iron, so as to form a parallelogram. Horseshoe magnets should have a short bar of soft iron adapted to connect the two poles, and should never be laid aside without such a piece of iron adhering to them.

(65) **General Principles.**—1. *Direction.*—If a bar of steel, magnetised by any of the processes above described, be suspended horizontally in a little stirrup of paper or metal, by a fibre of silk (Fig. 91); and if all bodies of a ferruginous nature be removed from its vicinity, it will, after a few oscillations, take up a position *nearly* north and south; and if disturbed from this position and placed in any other, it will not remain there, but as soon as it is at liberty to move it will resume its former position.

Fig. 91.

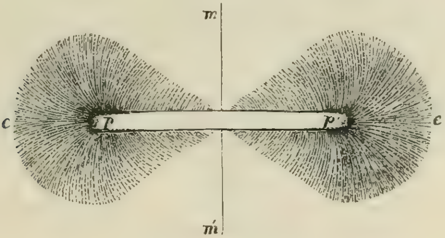


2. *Attraction and Repulsion.*—If two magnetised bars be poised, and placed in different positions with regard to each other, it is found that in some positions they appear to be attracted towards each other, while in others they manifest a mutual repulsion. This does not, however, happen capriciously; the two north poles and the two south poles invariably repel each other; but the north pole of one magnet always attracts and is of course attracted by the south pole of the other.

3. *Magnetic Poles.*—If a magnetised bar be sprinkled over with fine iron filings, the filings will be found to adhere to it in the form of bristling tufts, but by no means in a uniform manner; at the extremities, *ee* (Fig. 92), the iron filaments will be very long, standing out perpendicularly from the surface. As the centre of the bar is approached, they will become shorter, gradually taking up a more and more inclined position, and adhering in smaller and smaller tufts as the centre line *mm′* is approached. In the immediate neighbourhood of this line no filings are attracted; this, therefore, is called the *neutral line*, and the two halves of the bar *pp* are called the magnetic poles. Every magnet, natural or artificial, possesses essentially this neutral line, and these magnetic poles;

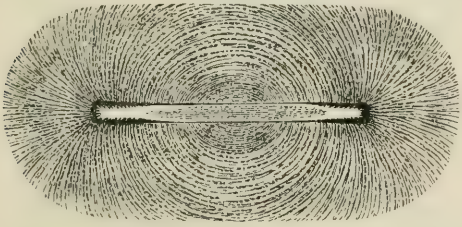
but it sometimes happens that a magnetised bar possesses more than two poles, two or more poles alternating between those situated at either extremity of the bar. A magnet in this condition is said to have '*consecutive*' poles.

Fig. 92.



4. *Magnetic Curves.*—If a magnetised bar be laid on a table, and covered with a sheet of white paper, or with a thin plate of glass, and iron filings sifted over it from a muslin bag, the filings will, on gently tapping the paper, arrange themselves round and about the poles of the bar in a very beautiful manner, forming a succession of curves known as the magnetic curves (Fig. 93), or 'curved lines of magnetic force' (*Faraday*). On examining these

Fig. 93.



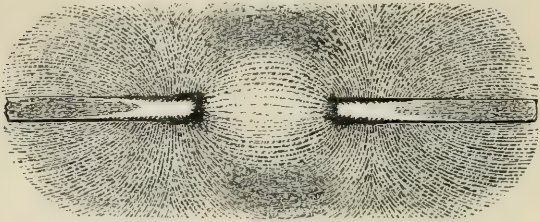
curves, it will be found that the force decreases gradually from the poles towards the centre, or some point intermediate between the two poles, where it vanishes altogether. This is the neutral point, or the *equator* of the magnet.

Beautiful visual evidence of the existence of two distinct magnetic forces, of their mutual attractions and repulsions, may be obtained thus:—

Let the two dissimilar poles of two powerful bars be placed in the same line, about one and a half or two inches apart, and let iron filings be sifted

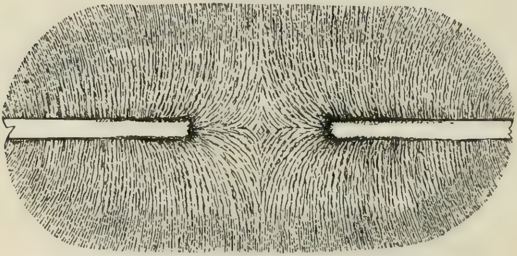
through a muslin bag on a frame of drawing paper placed over them; the filings will arrange themselves as shown in Fig. 94, the curved and straight

Fig. 94.



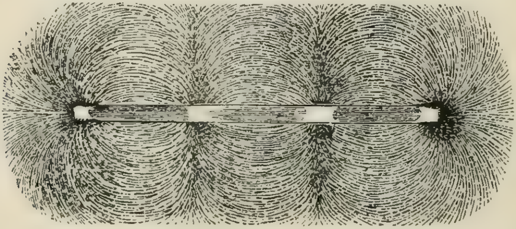
lines of magnetic force issuing from similar points of each bar joining the two poles, and showing reciprocal attractions. Then let the two similar

Fig. 95.



poles be placed opposite each other, and the filings again sifted over them; evidence of mutual repulsion will now be obtained, the lines of force being

Fig. 96.

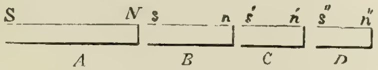


apparently conflicting, as shown in Fig. 95. If the bar have 'consecutive poles,' the filings will be arranged as in Fig. 96.

The fundamental properties of the magnetic curves were investigated mathematically by Dr. Roget (*Journal of the Royal Institution*, Feb. 1831). He describes them as having the following remarkable property : viz. That the difference of the cosines of the angles which lines drawn from any point in the curve to the two poles make with the axis taken on the same side, is constant; and he constructed a system of rules by which these curves may be mechanically delineated.

5. *Induction.*—In order to communicate magnetism from a natural or artificial magnet to unmagnetised iron or steel, it is not necessary that the two bodies should be in contact. The communication is affected as perfectly, though more feebly, when the bodies are separated by space. Thus, in Fig. 97, if the north pole

Fig. 97.



of an artificial steel magnet, A, be placed near the extremity, *s*, of a piece of soft iron, B, the end *s* will instantly acquire the properties of a south pole, and the opposite end *n* those of a north pole. The opposite poles would have been produced at *n* and *s* if the south pole S of the magnet A had been placed near the iron bar B.

In like manner B, though only temporarily magnetic, will render another piece of iron C, and this again another piece D, temporarily magnetic, north and south poles being produced at n' s' and n'' s''.

Here we observe a marked analogy between the phenomena of magnetic attraction and repulsion, and those of electrical attraction and repulsion. In both there exists the same character of double agencies of opposite kind, capable when separate of acting with great energy, and being when combined together perfectly neutralised, and exhibiting no signs of activity. As there are two electrical, so there are also two magnetic powers, and both sets of phenomena are governed by the same characteristic laws. Thus, in the above experiment, the magnetism inherent in B, C, D, is said to be *induced* by the presence of the real magnet A; and the phenomena are precisely analogous to the communication of electricity to unelectrified bodies by induction (7). When a magnet attracts a piece of iron, it does so by inducing an opposite polarity at the end adjacent to it, and the two opposite principles attract each other. So also when iron filings are attracted, the particle of iron next the magnet has magnetism induced on it, and it becomes a minute magnet like B, Fig. 97. This particle induces

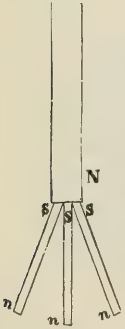
magnetism on the next particle like C, and so on, the opposite polarities in each particle of the filings attracting one another as if they were real magnets.

On comparing the amount of the *attractive* force of the two *dissimilar* poles of two magnets with the amount of the *repulsive* force of the two *similar* poles, it is found that the former force is considerably greater than the latter. This result is a necessary consequence of the inductive process above described. When the two attracting poles are in contact, each magnet tends to increase the power of the other by developing the opposite states in the adjacent halves, and thus increasing their mutual attraction. But when the two repelling poles are brought into contact, each magnet has a tendency to diminish the repulsive power of the other by developing in it a polarity contrary to that which it possesses. If one magnet be considerably stronger than the other, the repulsion which first takes place, on bringing their similar poles near each other, is changed to attraction when they are brought into contact, the strong magnet destroying the similar magnetism in the half of the weak magnet next to it, and inducing in it the opposite polarity.

The operation of magnetic induction may be well illustrated by the following experiments :—

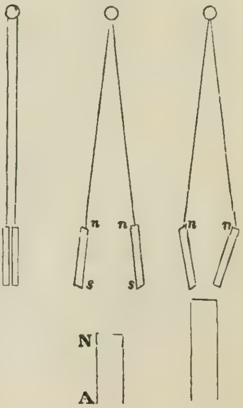
1. Let three or four soft iron wires be suspended from the N pole of a strong bar magnet; it will be found that they will not hang parallel to each other, but assume the position indicated in Fig. 98. The wires become temporarily magnetic, their S poles being determined towards and adhering to the N pole of the magnet; while the N poles not being under any restraining power, manifest a mutual repulsion and avoid one another, as shown in the figure.

Fig. 98.



2. Let two pieces of soft iron be suspended by threads from a ring or hook, and let the N pole of a strong bar magnet, A (Fig. 99), be held at a certain distance below them; the wires will become inductively magnetic, and their similar S poles being determined towards N, a mutual

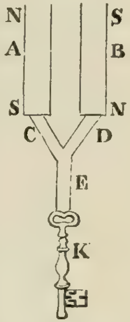
Fig. 99.



repulsion is set up. If, now, the magnet be brought very near, the repulsion of the *s s* ends of the wires gives place to an apparent attraction; this is caused by the strong attraction of A for both wires overcoming their own mutual repulsion; the repulsion of the *n* ends of the wires is, however, now rendered evident, and the nearer the inducing magnet is brought to the wires the stronger will this repulsion be manifested.

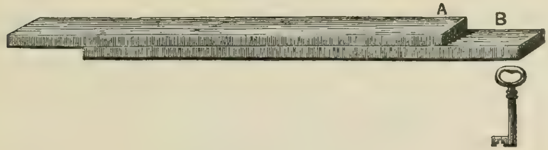
3. Let a forked piece of soft iron C D E (Fig. 100) be suspended by one of its branches from the N pole of the magnetic bar B; if the power of the bar be pretty strong, it will induce sufficient magnetism in C D E to enable it to hold in suspension the key K; but if we now bring into contact with the other branch of the fork the S pole of a second magnet A, the key will drop off, the reason being, that the N pole of B induces a northern polarity at the lower end E of the fork, hence its power of sustaining the key; but the S pole of A tends to give a southern polarity to the same end, and the two actions mutually destroy or neutralise each other.

Fig. 100.



4. Let a mass of soft iron, such as a key, be suspended from either pole of a strong magnet B (Fig. 101), and then let a second and similar magnet A be gradually slid over B, taking care that the opposite poles of the two bars shall come into contact. When the end of A arrives within a certain distance of B, the key will fall off as if the bar had lost its magnetic power; this however, is not the case, for on removing A the key may be again supported from B.

Fig. 101.



5. Let a word or a figure of any kind be traced with a powerful bar magnet with a round end on a well-tempered and polished steel plate; then let clean iron filings be shaken on the plate from a muslin bag; the filings will be found to arrange themselves in the empty spaces between the lines traced by the pole of the magnet, and thus represent on vacant steel the design that has been traced. If a south pole has been used, all the traces marked will have a north polar magnetism, and the filings collect at the parts where the magnetism is most intense, arranging themselves in pencils and radii. These magnetic figures were first produced by M. Haldat.

(66) **Qualities of Steel for Artificial Magnets.**—From the experiments of Scoresby, it would appear that for large or massive

single and compound magnets of the straight bar form, the best material is *hard cast steel*; for horseshoe magnets, if single, cast steel annealed from file hardness at a temperature of about 550°, or *shear steel* a little reduced; and for compound horseshoe magnets, cast steel annealed at 480° to 500°, or shear steel perfectly hard; for compass needles, if single and heavy, such as are suited for stormy weather, *hard cast steel*; if light or of moderate weight, whether single or compound, the best cast steel annealed at 500° or 550°, or hard shear steel, or hard cast steel from Bradford iron; and for very light needles, or other small magnets, the best cast steel annealed at the heat of boiling oil. Cast-iron (No. 1 pig metal) bars, if hardened at the end, are capable of forming powerful and permanent magnets. Hearder constructed a battery of twenty-four bars, each weighing 3 lbs., which was capable of lifting 60 lbs.

The practice of hardening the ends only of bars destined for magnets is not, according to the same authority, to be recommended, as this mode of tempering possesses no advantage as to capacity, while it has much disadvantage as to tenaciousness, except in very thin bars. A moderate hardening throughout is the most efficacious.

Scoresby found a constant relation between the *ductility* of iron and its magnetic capacity: the best iron possesses the highest magnetic quality. He examined magnetically all the varieties of steel, both hard and soft, and the results he obtained revealed such a relation between the magnetical properties of several bars and the denomination of steel of which they were made, as to show that it might not be impossible that magnetism may be rendered available for ascertaining not only the degree of carburation but even for determining the quality of iron out of which the steel may have been manufactured.

(67) **Most Advantageous form of Magnet.**—According to Lamont (*Pogg. Ann.*, vol. cxiii.), there are two forms which appear advantageous: the flat contracting to a point from the middle; and the flat prismatic; in the first form the proportion of the magnetism to the weight is greater by one-eighth part than in the latter, so that it must always hold as a rule that the thickness and breadth must be as much diminished as the other necessary conditions permit.

(68) **Laws of Magnetic Combinations; Magnetic Batteries.**—By combining the principle of the diffusion of energy by the combination of separate plates with that of selection by testing of powerful and tenacious plates, very powerful magnetic batteries may be constructed. Scoresby constructed a battery of 15-inch

hard plates, the power of which was five or six times as great as could be obtained from any combination in bars of similar length of plates of a *spring* temper only, the quality of steel usually employed. A *combination* of bars is proportionally more powerful than a single bar of equal weight; the absolute gain of power, however, gradually diminishes, and beyond a certain extent continued additions to a powerful combination is not only not beneficial but positively injurious. Advantage is gained by separating the plates by small discs; a larger number may then be employed. With regard to the degree of hardness, for all practical purposes, the limits may be considered as comprised between a brittle hardness like that of files, and that of a spring temper.

(69) **Directive Power of Magnetised Bars.**—For ascertaining this point, Coulomb employed his balance of torsion (Fig. 6, p. 6). Scoresby, however, recommends, as sufficiently exact for practical purposes generally, the method of deviations. The bars to be examined and compared are laid in a horizontal position, and at right angles to the magnetic meridian. A compass needle is suspended at a given distance, and the *tangents of deviation* produced by the bars to be tested afford, provided they are of the same length, a satisfactory estimate of their proportional powers. To ascertain the relative strength or tenaciousness of magnetic bars, compass needles, &c., Scoresby directs first to ascertain their directive energy separately, and then to bind them up into a bundle with their corresponding poles in contact; they are then to be taken apart and their directive energy again determined. Sometimes the bars have their poles reversed by this treatment. In this way surprising differences may be sometimes detected in bars apparently similar.

(70) **Laws of Magnetic Force.**—It was inferred by Newton, 'from some rude observations,' that the power of a magnet decreases not in the *duplicate*, but almost in the *triplicate ratio* of the distance. Hawksbee, Wilson, and Taylor gave a law of force which varies as the *sesquiduplicate* ratio of the distances; and Musschenbroek's researches led him to the conclusion 'that no assignable proportion exists between the forces and the distances, whether of attraction or repulsion.' Mayer and Martin considered the true law of the magnetic force to be identical with that of gravitation, according to the effective force which operates in restoring a needle to its meridian when drawn aside from it is directly as the line of the angle of its deflection. The law of force was found to be in the inverse duplicate ratio of the distances. The directive or polar force of a magnet upon a small needle was shown by Lambert to be as the absolute force or magnetic inten-

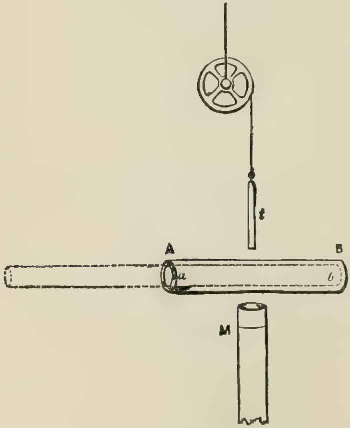
sity of the particles directly, and as the squares of the distances inversely. Lambert's deductions were subsequently confirmed by Coulomb.

According to the more recent inquiries of Harris (*Edinb. Phil. Trans.* 1839), there is a limit in respect to the elementary magnetic inductive forces different for different magnets, and varying with the magnetic conditions of the experiment; but as a general rule the elementary force of magnetic induction is as the magnetism directly, and from the $\frac{1}{2}$ or square root to the $\frac{3}{2}$ power or *sesquiduplicate ratio* of the distance inversely. Harris examined the forces at successive points of an accurately divided, powerfully magnetised, and equally tempered bar, by means of his hydrostatic balance, and found that the magnetism in different parts of a regularly tempered and magnetised steel bar of uniform texture was directly as the distance from the magnetic centre, while the reciprocal force between any given point and soft iron was as the square of the distance from that centre.

By the following instructive experiment, Harris has shown that magnetism, like electricity, is only influenced by the surface, and is independent of the mass of the magnetised body.

Between the magnet M (Fig. 102) and the trial rod *t* of the magnetometer a small cylinder of iron A B was placed, into which could be inserted, as a core, a closely fitting cylinder *a b*, also of iron. The magnet was placed at a convenient distance below the cylinder, and the attractive forces on the trial rod were measured when the interposed cylinder was hollow, when the core was in its place, and when it was drawn out, as represented by the dotted lines in the figure, so as to double the extent of the interposed surface. When the joint cylinders were taken together as a mass, and when the interior cylinder was removed, the force was in both cases the same; but when the core was drawn out, so as to extend the surface to the greatest limit, the intensity was diminished one-half.

Fig. 102.



Tyndall has also investigated the laws of magnetism (*Phil. Mag.*, new series, vol. i. p. 295). The principal results of his inquiry are the following:—

1. The mutual attraction of a magnet and a sphere of soft iron, when both are in contact, is directly proportional to the strength of the magnet.

2. The mutual attraction of a magnet and a sphere of soft iron, when both are separated by a small fixed distance, is directly proportional to the *square* of the strength of the magnet.

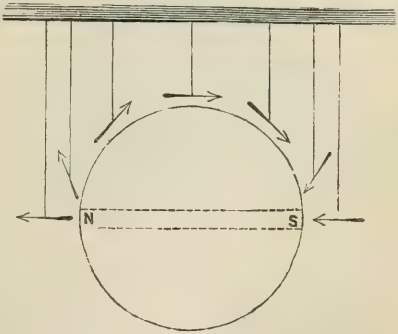
3. The mutual attraction of a magnet of constant strength, and a sphere of soft iron, is *inversely* proportional to the distance between the magnet and the sphere.

4. When the distance between the magnet and the sphere varies, and a constant force opposed to the pull of the magnet is applied to the latter, to hold this force in equilibrium, the strength of the magnet must vary as the square root of the distance.

(71) **Terrestrial Magnetism.**—The earth must be regarded as a magnetic mass operating on the magnetic needle precisely in the same way as one magnetic mass operates on another. The total magnetic power, or 'moment magnetism,' of the earth, as compared with that of a saturated steel bar one pound in weight, was calculated by Gauss to be as 8,464,000,000,000,000,000,000 to 1; which, supposing the magnetic force to be uniformly distributed, will be found to amount to about six such bars to every cubic yard.

If we communicate magnetism to a steel bar which in its neutral condition has been exactly equipoised when suspended freely from its centre, we shall find that it no longer maintains its horizontal position, but assumes an oblique one, being inclined with its north pole downwards at an angle of about 68·15°. If we take this needle to different parts of the earth, we shall find its inclination to be different in different parts, the angle becoming greater and greater as we approach the poles, and less and less as we approach the equatorial regions.

Fig. 103.

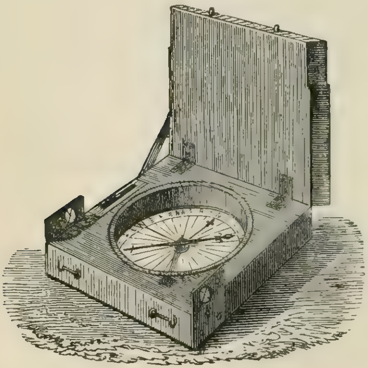


The magnetic condition of the globe may be illustrated thus:—

Let a bar magnet be enclosed in a light wooden or pasteboard sphere (Fig. 103), and let a light magnetic needle be suspended by a thread, and held over the equator of the sphere, it will assume a horizontal position, its north pole pointing towards the south pole of the enclosed magnet; let the needle then be moved gradually over the surface of the globe, and it will be found to assume the different positions indicated in the figure, in which the north pole of the suspended needle is distinguished by an arrow head.

(72) **The Land Compass.**—The magnetised needle is placed upon a point in the centre of a brass or wooden box furnished with a graduated ring. The box is furnished with two straight edges of brass, or index marks to set to any proposed line, and sometimes with sights, the top being covered with glass to prevent the needle from being disturbed by the action of the air. There are also two small pieces of brass, one of them turning upon a fixed point, which is used to check the oscillation of the needle by pressing on its upper end; the ring at the other end of the lever is raised till it touches the needle, which is thereby rendered steady; the lever is then let down, and the needle left to find its proper direction. In the figure (Fig. 104) the needle is mounted with a card divided into points and quarter-points of the compass, the N. and S. points being made to correspond very exactly with the needle; in this form the general direction of an object will be known by observing its bearing, which will always be in accordance with the magnetic meridian of the place of observation.

Fig. 104.

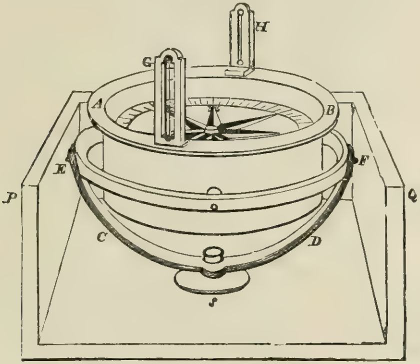


(73) **The Mariner's Compass.** — In the ordinary form it consists of a magnetic needle attached to a circular card, the surface of which is divided into the four cardinal points N., S., E., and W. These again are sub-divided into thirty-two points, which are called *rhumbs.* In the azimuth compass the circle is divided into 360 parts. The position of the needle is usually estimated in terms of the thirty-two points, but in refined experiments the angular deviation of the needle from the line of

the magnetic meridian is measured in degrees and minutes taken in reference to either the N. or S. pole of the card. Thus, instead of rhumb SW., we say S. 45° W.; instead of ENE., we say N. 67° 30′ E., and so on.

The azimuth compass is shown in Fig. 105; the compass box A B is suspended within a large box, P Q, upon two concentric brass circles or *gimbals*, the outer circles being both fixed by horizontal pivots to the inner circle which carries the compass box; the two axes upon which the gimbals

Fig. 105



move being at right angles to each other. The effect of this construction is, that the compass box A B will retain a horizontal position during the motions of the vessel. The compass box is furnished with sights, G H; through which any object may be seen, and its angle with the magnetic meridian increased.

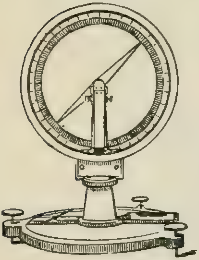
For this purpose the whole box is hung in detached gimbals, C D, E F, which turn upon a stout vertical pin, seen above S. In this compass the card is divided on its rim into 360°, but the divisions are more frequently placed on a light metallic rim which it carries. The eye is applied to the sight H, which is a strip of brass containing a narrow slit. The other sight G, which is turned towards the object, contains an oblong aperture, along the axis of which is stretched a fine wire, which is made to pass over the object whose angular distance or *azimuth* from the magnetic meridian is to be determined.

The compass recommended by the Committee of Enquiry appointed by the Admiralty consists of four compound magnetic bars secured together with a card within a light ring of brass; the card is made of mica, and covered with thin paper, on which the impression of the cardinal points is printed; the caps are of agate or ruby; and the points of suspension of native alloy; the bowl is made of copper.

(74) **The Inclination Compass.**—The important fact that a magnetised needle, when allowed perfect freedom of motion, endeavours to place itself in the plane of the magnetic meridian in a direction more or less inclined to the horizon, was discovered about the year 1756 by Robert Norman, an optician of London, but many years elapsed before it was known that this inclination of the needle was subject to a variation. This interesting fact has, however, been well ascertained, and instruments called *dipping needles* have been constructed, with a view of ascertaining the amount of the inclination in different places at the same time; or in the same place at different times; but it was not until the latter end of the last century that sufficient accuracy could be carried into their construction to render them fully competent to the delicate task they were intended to perform.

A simple form of dipping needle is shown in Fig. 106. It consists of a brass plate supported on a flat stand by three screws; on this plate is placed a spirit-level for adjusting the plate horizontally; a stout hollow brass pillar rising from the centre of the plate carries a circular box, forming the case of the dipping needle, which turns freely on two finely polished planes of agate.

Fig. 106.



It is very rarely, however, that a needle can be so nicely balanced as to give the exact dip at a single observation. The usual mode of proceeding is, therefore, as follows:—Having taken eight or ten observations, turn the needle completely round, viz. if in the first instance the face was towards E., turn it now to W.; if it was before W., turn it to E.; this is very easily effected by the graduations on the lower limb of the instrument. Let the same number of observations be again taken, they may not agree precisely with the first in consequence of some defects in the construction of the instrument; let, however, the mean in both cases be preserved by dividing the sum of each set of observations by the number of them. The needle is now to be removed from the box, and its poles inverted by any of the usual methods of magnetising, so that when replaced on its axis, that end which was before below the horizon will now be above it, and if the needle be correctly balanced, by exactly the same quantity; but not, as is most likely to happen, two other means must be got as before, and the general mean of the four will be very nearly or exactly the true dip.

(75) **The Variation Compass.**—This instrument being

intended for measuring small changes in the declination of the magnetic needle, either annual or diurnal, is more limited in its arc of vibration, and is generally longer than the needle used for common purposes; it is also furnished with conveniences for reading closer than the ordinary compass. The needles intended for this purpose are usually constructed in a particular manner, having only a very small part of the circle graduated, and the means of distinguishing small changes better suited to the eye than they generally are in common horizontal needles. The place in which the instrument is fixed is required to be particularly firm and steady, and, in short, every precaution is necessary to be had recourse to in order to avoid small irregularities, because the changes to be observed are themselves so small that without the greatest accuracy they may be either overlooked, or the irregularities of the instrument may so combine them, that every attempt to deduce laws from them would be unavailing.

(76) **The Declination Magnet.**—This instrument, for determining the direction of the needle and its variations, consists of a prismatic magnetic bar suspended by untwisted threads of raw silk. To the south or north end of the bar a plane mirror is fixed, and it is enclosed in a wooden cylindrical box, which, besides the small aperture in the lid for the passage of the thread, has a larger one in the side, which is rather higher and wider than the mirror. Opposite the mirror a theodolite is placed, the vertical axis of which is in the same magnetic meridian with the line of suspension, and at a distance from it of about 16 Parisian feet. To the stand of the theodolite is fixed a horizontal scale of 4 feet in length, divided into single millimetres; it makes a right angle with the magnetic meridian. That point of the scale which is situated in the same vertical plane with the optical axis of the telescope, and which may be called the zero point, is marked out by a fine thread of gold depending from the middle of the object glass, and charged with a weight. The scale is fixed at such a height that the image of a portion of it is seen in the mirror through the telescope, the eye glass of which is adjusted accordingly. At the opposite side of the needle, in the same vertical plane, and at a distance from the telescope equal to that of the image, a mark is fixed serving every instant to ascertain the unchanged position of the theodolite. It is obvious that if all these conditions be fulfilled, the image on the zero point of the scale will appear exactly on the optical axis of the telescope, and that so far as an object of known azimuth is visible at the place of the theodolite, we may by means of this instrument immediately find the absolute magnetic declination. If, on the other hand, these conditions are only partially fulfilled,

then, generally speaking, the image, not of the zero-point, but that of another point of the scale will appear on the optical axis; and if the horizontal distance of the scale from the mirror has been measured with exactness, it will be easy to reduce the amount of the divisions of the scale to the corresponding angle, and thus to correct the result first obtained. By turning the needle in the stirrup, so that the upper surface becomes the lower, the amount of the error of collimation of the mirror may be ascertained with great ease and precision. By this mode of operating, the direction of the needle and its variations are determined with great precision.

(77) **The Variation of the Needle.**—Measures of the variation of the magnetic needle have been taken by travellers and navigators in all parts of the globe. In some places the magnetic and terrestrial meridians exactly correspond; in these situations the needle points to the true north and south, but in most parts of the earth's surface its direction deviates sometimes to the E. and sometimes to the W. Hansteen makes the *western line of no variation*, or that which passes through all the places on the globe where the needle points to the true N., to begin in latitude 60° to the W. of Hudson's Bay, proceeding in a SE. direction through the North American Lake, passing the Antilles and Cape St. Roque till it reaches the South Atlantic Ocean, where it cuts the meridian of Greenwich at about 65° of S. latitude. This line of no variation is extremely regular, being almost straight till it bends round the eastern part of South America, a little S. of the equator. On the other hand, his chart shows that the eastern line of no variation is extremely irregular, being full of loops and inflexions of the most extraordinary kind, indicating the action of local magnetic forces. It begins in latitude 60° S., below New Holland, crosses that immense island through its centre, extends through the Indian Archipelago with a double sinuosity, so as to cross the equator three times; first passing N. of it to the E. of Borneo, and then crossing it again beneath Ceylon, from which it passes to the E. through the Yellow Sea. It then stretches along the coast of China, making a semicircular sweep to the W. till it reaches the latitude 70°, where it descends again to the S., and returns northward with a great semicircular bend which terminates in the White Sea. These lines of no variation are called *agonic lines*.

In 1833 Professor Barlow constructed a new variation chart, in which he inserted the magnetic observations of Commander Ross; and he remarks that 'the very spot where this officer found the needle perpendicular—that is, the pole itself—is precisely that point in my globe and chart in which, by supposing all the lines to meet

the several curves, would best preserve their unity of character, both separately and conjointly, as a system.'

The following table exhibits the progressive changes in the variation of the needle which have taken place in London from 1576 to 1871 :—

Year.	Observer.	Variation.
1576	Norman	11° 15′ E.
1580	Burroughs	11 17 „ (Max.)
1622	Gunter	6 12 „
1634	Gellibrand	4 5 „
1657, 1662		No variation.
1666		0 34 W.
1670		2 6 „
1672		2 30 „
1700		9 40 „
1720		13 0 „
1740		16 10 „
1760		19 30 „
1774		22 20 „
1778		22 11 „
1790		23 39 „
1800		24 36 „
1806		24 8 „
1813	Colonel Beaufoy	24 20 17″ W.
1815	„	24 27 18 „ (Max.)
1816		24 17 9 „
1820		24 11 7 „
1823		24 9 40 „
1831		24 0 0 „
1841	Greenwich	23 16 2
1851	„	22 18 3
1861	„	21 5 5
1871	„	19 41 9

From this table it appears that the needle began to have a westerly variation from 1662, and that it reached its maximum about 1815, since which it has been retrograding; and now (1877) it points 19°·5′ west of the north.

At the present time the whole of Europe, with the exception of a small part of Russia, has a W. declination. In Eastern Russia, to the E. of the mouth of the Volga, of Saralow, Nishni-Novogorod, and Archangel, the easterly declination of Asia is advancing towards us. There are particular parts of the earth's surface, as in the Western part of the Antilles and in Spitzbergen, where the mean declination of the needle has scarcely undergone any sensible change in the course of the last hundred years. Since 1660 the compass has been permanent in Jamaica.

'The whole mass of West India property,' remarks Sir John Herschel (*Cosmos, Sabine's Translation*, vol. i. p. 410), 'has been saved from the bottomless pit of endless litigation by the invariability of the magnetic declination in Jamaica and the surrounding archipelago, as during the whole of the last century all surveys of property were conducted solely by the compass.'

(78) **The Inclination of the Needle.**—The dip of the magnetic needle, like the variation, undergoes a continual change, increasing in some parts of the world and diminishing in others. The following table shows the changes of the dip at London between 1720 and 1833:—

Year.	Observed.	Observer.	Computed.
1720	74° 42″	Graham	76° 27′
1773	72 19	Heberden	73 40
1780	72 8	Gilpin	73 18
1790	71 53	,,	72 39
1800	70 35	,,	71 58
1810	. .	.	71 15
1818	70 34	Kater	70 34
1821	70 3	Sabine	. .
1828	69 47	,,	69 43
1830	69 38	,,	. .
1833	. .	.	69 21

From this table it appears that the magnetic dip reached its maximum in London in 1720. From observations made at the Kew Observatory in May 1863, the dip was 68° 15′, so that during the last 143 years it has lost 6° 27′, being at the rate of 2′ 7″ each year. At Toronto, the inclination on March 11, 1847, was 75° 16′.

(79) **Periodic Variations of the Magnetic Needle.**—(*a*) *Annual Variation.*—The horizontal needle is subject to *annual* variations, depending on the position of the sun in reference to the equinoctial and solstitial points, and to *horary* variations corresponding to changes of temperature from the diurnal rotations of the earth.

Between the months of January and April the needle recedes from the N. pole of the globe, so that its western declination increases.

From April to the beginning of July—that is, from the vernal equinox to the summer solstice—the declination diminishes or the needle approaches the N. pole of the globe.

From the summer solstice to the vernal equinox, the needle receding from the N. pole returns to the W., so that in October it has nearly the same position as in May; and between October and March the western motion is smaller than in the three preceding months. Hence it follows that during the three months between

the vernal equinox and the summer solstice the needle retrogrades towards E., and during the following nine months its general motion is towards W.

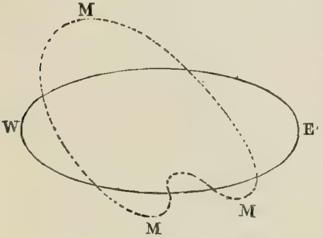
(*b*) *Daily Changes in the Variations.*—This was first observed in 1724, by Mr. Graham, and has been confirmed with the most accurate instruments in almost every part of the world. Sabine has arranged and presented together (*Phil. Trans.* 1851) the variations which the declination undergoes at every hour of the day at the four colonial observatories established by the British Government; viz. at Toronto, from three years' observation; at Hobarton, from five years' observation; at the Cape of Good Hope, from five years' observation; and at St. Helena, from three years' observation. The range of variation at all the four stations is considerably greater during the hours of the day than during those of the night, and a great similarity, though not a perfect identity, is observed at all the stations in the relative amount of the range at different hours. It further appears that the amount does not progressively enlarge to a maximum at or about noon, when the sun's altitude is greatest, or at the early hours of the afternoon, when the temperature is greatest, but that at all the stations the increase in the range is most rapid in the first or second hour after sunrise, and that its extent at the hours from 7 to 9 A.M. is not exceeded at any subsequent hour at Hobarton, the Cape, and St. Helena, whilst at Toronto the great enlargement takes place even earlier, the hours of 6, 7, and 8 A.M. being exceeded by none, though they are equalled by a second increase at noon and the two following hours. The second enlargement is perceptible at the same hour at Hobarton and St. Helena.

From a series of observations taken every two hours, day and night, for between two and three years, at the Dublin Observatory, under the direction of Professor Lloyd, it appears that the mean daily curve of the changes of declination for the entire year exhibits a small easterly movement of the N. end of the magnet during the morning hours, which reaches its maximum about 7 A.M.; after that hour the N. end moves rapidly W., and reaches its extreme westerly position at 1 hr. 10 m. P.M. It then returns eastward, but less rapidly, the easterly deviation becoming a maximum about 10 P.M., the mean daily range being equal to 9′ 8″. During the summer months the morning maximum at 7 A.M. is more marked; the evening maximum, on the contrary, disappears, there being a slow and regular movement of the N. end to the eastward from 7 P.M. until 7 A.M. In winter, on the other hand, the evening maximum is well defined and the morning maximum disappears, there being a slow and regular westerly movement until

9 A.M., after which the movement becomes more rapid in the same direction. The epoch of the extreme westerly position of the magnet is nearly the same throughout the year. The greatest daily change in summer is about 13′ 7′ ; the least range in winter about 7′ 2″.

(80) **The Magnetic Equator.**—This is an irregular line crossing the terrestrial equator at four points, as shown in Fig. 107, where the black line W E is intended to represent the real equator, and the dotted line M M M the magnetic equator, crossing the former at four points instead of two, and showing the evident existence of some great disturbing cause.

Fig. 107.



'The magnetic equator,' observes M. Duperrey (*Annales de Chimie*, 1830), 'will meet the equinoctial line only in two points which are diametrically opposite, the one situated in the Atlantic Ocean and the other in the Great Ocean nearly in the plane of the meridian of Paris. When this equator meets only some scattered islands, it recedes only a little from the equinoctial line; when the islands are more numerous, it recedes further; and it reaches its maximum deviation in both hemispheres only in the two great continents which it traverses. It is found, also, that between the northern and southern halves of the magnetic equator there is a symmetry very remarkable, and much more perfect than had previously been believed.

'The dip of the needle increases on each side of the magnetic equator; and Hansteen has projected lines of equal dip in his chart These lines are nearly parallel to the magnetic equator till we reach 60° north latitude; they then begin to bend round the American magnetic pole, which Sir James Clark Ross found to be situated in N. latitude 70° 5′ 17″, and in W. longitude 96° 45′ 48″, the needle having at this point, in Boothia Felix, lost wholly its directive power, and the dip being 89° 59′ within one minute of 90° or vertical. Had we inferred the position of the needle from the form of the magnetic equator, we should have placed it in 25° of W. longitude; viz. the meridian on which the magnetic equator advances further to the S., or about $13\frac{1}{2}°$, and $76\frac{1}{2}°$ of N. latitude, or $90-13\frac{1}{2}°$. This, however, as all Arctic observations prove, is not the case, and we are led by the phenomena of the dip, as well as by those of the variations in different parts of the globe, to conclude that every place has its own magnetic axis, with its own pole and its own equator.'

(81) **Terrestrial Magnetic Intensity.**—If a needle whose axis of suspension passes through its centre of gravity, and which has its N. and S. polar magnetism equal and similarly distributed,

be made to vibrate, by turning it from its position and allowing it to recover that position by a series of oscillations, it is evident that the magnetism of the earth will act with equal force on each half, and that the needle will be drawn into the magnetic meridian by the combined action of both forces. The greater the magnetic force, the more quickly will the needle oscillate and recover its primitive position. The needle is, in short, in the same circumstances as a pendulum oscillating by the action of gravity; and, as in this case, the forces are as the *squares* of the numbers of oscillations made in the same time.

Suppose a dipping needle be made to oscillate in the plane of the magnetic meridian round the line of dip, and that when an experiment is made at the equator the number of oscillations in a second is 24, while in another place it is 25; then the intensity of the magnetic force at these places is as 25^2 to 24^2, or as 625 to 576, or as 1·085 to 1·000. By carrying the same needle to different parts of the earth, the *magnetic intensity* at these places will be found from the number of oscillations.[1]

The magnetic intensity, like the variation and dip of the needle, undergoes diurnal and monthly changes. Hansteen found that the *minimum* of daily change of intensity is between 10 and 11 A.M., and the *maximum* between 4 and 7 P.M. in May, and about 7 P.M. in June. The intensity is a maximum in December and a minimum in June. The greatest monthly change in the intensity is a maximum in the months of December and June, about the time when the earth is in its perihelion and aphelion. It is a minimum near the equinoxes or when the earth is at its mean distance from the sun. The greatest daily change is least in the winter and greatest in the summer. The greatest difference of the annual intensity is 0·0359. Hansteen likewise found that the magnetic intensity is diminishing in Europe, and that the decrease is greater in the northern and eastern than in the southern and western parts, an effect which he conceives to be produced by the motion of the Siberian pole towards the E.

From the researches of Sabine and others, it appears that there are two foci or points of maximum force in each hemisphere round which the *iso-dynamic* lines (lines of equal magnetic force) circulate in an ovate form; these foci are not of equal force in either hemisphere; the focus of greater intensity in the northern hemisphere is in North America, in the vicinity of the SW. shores of Hudson's Bay, in 52° 19′ N. latitude, the intensity being 1·88;

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[1] For a description of Harris's 'Magnetometer of Oscillations,' see *Edinb. Phil. Trans.*, vol. xiii. pt. i., and *Trans. Royal Soc.*, 1831

the weaker force is in the north of Siberia, about 120° of east longitude from Greenwich, with an intensity of 1·76. The principal maximum focus in the southern hemisphere was found by Sir James Ross, in 1840–3, in about the meridian of 134° E., and a few degrees N. of the Antarctic circle, while the weaker maximum, according to Sabine, is about 130° W. The ratio of the magnetic force at the major focus in North America, as determined by Lefroy, is 13·9, at the minor focus in Siberia, from the observations of Hansteen and Duc, 13·3; at St. Helena, which is the weakest part of the line of least intensity, its value is 6·4. At London at the present time the magnetic intensity is 10·31. The unit of force in this scale is that amount of magnetic force which, acting on the unit of mass through the unit of time, generates in it the unit of velocity, and the units are taken respectively as a grain, a second, and a foot British measure.

(82) **Magnetic Storms.**—This term was applied by Humboldt to certain fitful agitations of the needle, which he was the first to notice at Berlin in 1806. The phenomenon has since much engaged the attention of magneticians. In 1818 a magnetic storm, shown by a violent agitation of the needle, took place simultaneously over 47° of longitude; and on the 25th of September, 1841, one of these storms was simultaneously observed at Toronto, at the Cape of Good Hope, Prague in Europe, and Macao in China, and there is reason to believe that it extended to Van Diemen's Land. Similar storms have happened simultaneously in Sicily and at Upsala in Sweden.

Magnetic storms are always accompanied by auroræ and earth currents—that is, currents of electricity which traverse the surface of our globe, a portion of which is caught up by the telegraphic wires, frequently occasioning serious disturbance in their communications.

It is the opinion of magneticians that the sun is the agent which causes the disturbances. Professor Schwabe, of Dessau, has now for nearly forty years been watching the disc of the sun and recording the groups of spots which have been visible, and he finds that these have a period of maximum nearly every ten years, two of these periods being the years 1848–1859. Now it was likewise found by General Sabine that the aggregate value of magnetic disturbances at Toronto attained a maximum in 1848, nor was he slow to remark that this was also Schwabe's period of maximum sun-spots, and it was afterwards found by observations made at Kew that 1859 (another of Schwabe's years) was also a year of maximum magnetic disturbance. 'There is some reason,' observes Balfour Stewart (*Pro. Royal Inst.*, vol. iv. part i. p. 57), 'to be-

lieve that on one occasion our luminary was caught in the very act. On the 1st of September, 1859, two astronomers, Messrs. Carrington and Hodgson, were independently observing the sun's disc, which exhibited at that time a very bright spot, when about a quarter past eleven they noticed a very bright star of light suddenly break out over the spot and move with great velocity across the sun's surface. On Mr. Carrington referring afterwards to Kew Observatory, at which place the position of the magnet is recorded continuously by photography, it was found that a magnetic disturbance had broken out at the very moment when this singular appearance had been observed.'

With respect to the bond which connects sun-spots with magnetic disturbances, no conjecture has been formed, but the fact, as Stewart observes, 'is eminently suggestive, and brings us at once into the presence of some great cosmical bond different from gravitation, adding, at the same time, new interest and mystery to these perplexing phenomena.'

The following remarks with regard to 'terrestrial magnetism' and 'terrestrial electricity' will conclude this interesting subject:—

'As to terrestrial magnetism, of what its relation may be to perceptible electric manifestations we at present know nothing. You all know that the earth acts as a great magnet. Dr. Gilbert, of Colchester, made that clear nearly 300 years ago; but how the earth acts as a great magnet—how it is a magnet—whether an electro-magnet in virtue of currents revolving round under the upper surface, or whether it is a magnet like a mass of steel or loadstone, we do not know. This we do know, that it is a variable magnet, and that a first approximation to the variation consists in a statement of motion round the axis of figure—motion of the magnetic poles round the axis of figure, in a period of from 900 to 1,000 years. The earth is not a uniformly magnetised magnet with two poles, and with circles of symmetry round those poles. But a first expression—as we should say in mathematical language, the first "harmonic term"—in the full expression of terrestrial magnetism is an expression of a regular and symmetrical distribution such as I have indicated. Now, this is quite certain, that the axis of this first term, so to speak, or this first approximation, which, in fact, we might call the magnetic axis of the earth, does revolve round the axis of figure.

'When the phenomena of terrestrial magnetism were first somewhat accurately observed about 300 years ago, the needle pointed here in England a little to the east of north; a few years later it pointed due north; then, until about the year 1820, it went to the west of north; and now it is coming back towards the north. The dip has experienced corresponding variations. Well, when the dip was first discovered by Robert Norman it was less than it is now. The dip has gone on increasing, and is still increasing; but about fifty years ago the deviation from true north was greatest. Everything goes on as if the earth had a magnetic pole revolving at a distance of about twenty degrees round the true north pole. About 300 years ago it was on the farther side of the north pole, and a little to the east. Thence it travelled round the north pole in the same direction as

that in which the earth itself rotates, so as to come to the left-hand side of the north pole, and then obliquely towards us: so that about 200 years from now we may expect the magnetic pole to be between England and the north pole, and in England the needle to point due north, and the dip to be greater than it has been for one thousand years, or will be again for another. That motion of the magnetic pole in a circle round the true north pole has already (within the period during which somewhat accurate measurements have been made) been experienced to the extent of rather more than a quarter of the whole revolution. It is one of the greatest mysteries of science—a mystery which I might almost say is to myself a subject of daily contemplation—what can be the cause of this magnetism in the interior of the earth? Rigid magnetisation, like that of steel or the loadstone, has no quality in itself in virtue of which we can conceive it to migrate round in the magnetised bar. Electric currents afford the more favoured hypothesis; they are more mobile. If we can conceive electric currents at all, we may conceive them flitting about. But what sustains the electric currents? People sometimes say, heedlessly or ignorantly, that thermo-electricity does it. We have none of the elements of the problem of thermo-electricity in the state of underground temperature which could possibly explain, in accordance with any knowledge we have of thermo-electricity, how there could so be sustained currents round the earth. And if there were currents round the earth, regulated by some cause so as to give them a definite direction at one time, we are as far as ever from explaining how the channel of these currents could experience that great revolutionary variation which we know it does experience. Thus we have merely a mystery. It would be rash to suggest even an explanation. I may say that one explanation has been suggested. It was suggested by the great astronomer Halley, that there is a nucleus in the interior of the earth, and that the mystery is explained simply by a magnet not rigidly connected with the upper crust of the earth, but revolving round an axis differing from the axis of rotation of the outer crust, and exhibiting a gradual processional motion independent of the processional motion of the outer rigid crust. I merely say that has been suggested. I do not ask you to judge of the probability; I would not ask myself to judge of the probability of it. No other explanation has been suggested.

'But now, I say we look with hopefulness to the practical telegraphist for data towards a solution of this grand problem. The terrestrial magnetism is subject, as a whole, to the grand circular variation which I have indicated. But, besides that, there are annual variations and diurnal variations. Every day the needle varies from a few minutes on one side to a few minutes on the other side of its mean position, and at times there are much greater variations. What are called "magnetic storms" are of not very unfrequent occurrence. In a magnetic storm the needle will often fly twenty minutes, thirty minutes, a degree, or even as much as two or three degrees sometimes, from its proper position—if I may use that term—its proper position for the time: that is, the position which it might be expected to have at the time according to the statistics of previous observations. I speak of the needle in general. The ordinary observation of the horizontal needle shows these phenomena. So does observation on the dip of the needle. So does observation on the total intensity of the terrestrial magnetic force. The three elements, deflection, dip, and total intensity, all vary every day

with the ordinary diurnal variation, and irregularly with the magnetic storm. The magnetic storm is always associated with a visible phenomenon, which we call, habitually, electrical; aurora borealis, and, no doubt, also the aurora of the southern polar regions.

'We have the strongest possible reasons for believing that aurora consists of electric currents, like the electric phenomena presented by currents of electricity through what are called vacuum tubes, through the space occupied by vacuums of different qualities in the well-known vacuum tubes. Of course the very expression "vacuums of different qualities" is a contradiction in terms. It implies that there are small quantities of matter of different kinds left in those nearest approaches to a perfect vacuum which we can make.

'It is known to you all that aurora borealis is properly comparable with the phenomena presented by vacuum tubes. The appearance of the light, the variations which it presents, and the magnetic accompaniments, are all confirmatory of this view, so that we may accept it as one of the truths of science. Well, now - and here is a point upon which, I think, the practical telegraphist not only can, but will, before long, give to abstract science data for judging—is the deflection of the needle a direct effect of the auroral current, or are the auroral current and the deflection of the needle common results of another cause? With reference to this point, I must speak of underground currents. There, again, I have named a household word to every one who has anything to do with the operation of working the electric telegraph, and not a very pleasing household word, I must say. I am sure most practical telegraphers would rather never hear of earth currents again. Still we have got earth currents; let us make the best of them. They are always with us; let us see whether we cannot make something out of them, since they have given us so much trouble.

'Now, if we could have simultaneous observations of the underground currents, of the three magnetic elements, and of the aurora, we should have a mass of evidence from which, I believe, without fail, we ought to be able to conclude an answer more or less definite to the question I have put. Are we to look in the regions external to our atmosphere for the cause of the underground currents, or are we to look under the earth for some unknown cause affecting terrestrial magnetism and giving rise to an induction of those currents? The direction of the effects, if we can only observe those directions, will help us most materially to judge as to what answer should be given.'—*Sir William Thomson.*

CHAPTER VII.

ELECTRO-PHYSIOLOGY.

The Discovery of Galvani—The Discovery of Volta—The Researches of Matteucci and Du Bois Reymond—Electric Fishes—Electricity of Plants.

(83) **The Discovery of Galvani.**—That remarkable form of electricity known by the name of galvanism, or galvanic electricity, is said to owe its origin to an accidental circumstance connected with some experiments on animal irritability which were being carried on by M. Galvani, a professor of anatomy at Bologna, in the year 1790.

'It may be proved,' says Arago, 'that the immortal discovery of the Voltaic pile arose in the most immediate and direct manner from a slight cold with which a Bolognese lady was attacked in 1790, for which her physician prescribed the use of *frog broth*.'

'When one of Galvani's pupils,' writes the author of the article 'Voltaic Electricity' in the *Encyclopædia Britannica*, 'was using an electrical machine, a number of frogs were lying skinned on an adjoining table for the purpose of cookery. The machine being in action, the young man happened to touch with a scalpel the nerve of the leg of one of the frogs, when, to his surprise, the leg was thrown into violent convulsions.'

'A person acquainted with the well-known laws of induced electricity,' writes Dr. Thomas Young (*Lectures on Natural Philosophy*), 'might easily have foreseen this effect.'

'Luckily for the progress of science,' observes Dr. Lardner (*Cabinet Cyclopædia*), Galvani was more of an anatomist than an electrician, and he beheld with sentiments of unmixed wonder the manifestations of what he believed to be a new principle in the animal economy. . . . . Chance now came upon the stage. In the course of his researches, he had occasion to separate the legs, thighs, and lower parts of the body of the frog from the remainder, so as to lay bare the lumbar nerves. Having the members of several frogs thus dissected, he passed copper hooks through part of the dorsal column which remained above the junction of the thighs for the convenience of hanging them up. In this manner he happened to suspend several upon the iron balcony in front of his laboratory, when, to his inexpressible astonishment, the limbs were thrown into strong convulsions. No electrical machine was now present to exert any influence.'

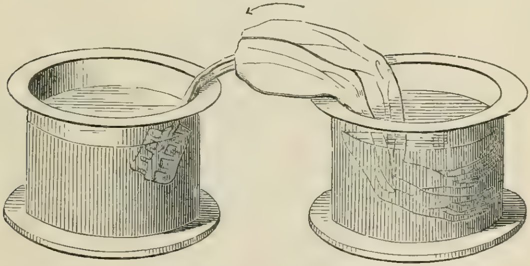
It would appear, however, from documents in the possession of the Institute of Bologna, that Galvani was occupied with experiments on the contractions of the muscles of frogs at least twenty

years before the publication of his famous '*Commentary*,' and that he was not unacquainted with electricity may be inferred from his suggestion that the contraction of the frog may be explained by the 'return shock,' and to his having written a Latin memoir on electrical light in air of different densities; and as for his feeling surprised on observing the contraction of a prepared frog when a spark from an electrical machine was taken to it, it is unfair to question his electrical knowledge from this fact; any other philosopher, as Matteucci (*Phénomènes Electro-physiologiques des Animaux*) justly observes, would at that time have felt surprised on witnessing the phenomenon for the first time.

The first experiment with a metallic arc is described in the third part of Galvani's *Commentary*. The note in which it is found registered bears date Sept. 20, 1786, and contains, in Galvani's own handwriting, the words '*Experiments on the Electricity of Metals*.'

The primary fact of the contraction of the frog suspended by a *copper* hook from an *iron* stem in the neighbourhood of an electrical machine in action, was studied by Galvani with great care. He observed that the contractions took place when the extremities of a metallic arc, formed of two different metals united together, touched at one point the nerves and at the other the muscles of the frog. In two parts of his *Commentary*, Galvani insists on the advantage in this experiment of employing a metallic arc composed

Fig. 108.



of two *different* metals instead of one. He also states that the contractions may be obtained by uniting with a metallic arc two capsules filled with water, in which the frog is so disposed as to have its lumbar nerves in one of the capsules and its legs in the other, as shown in Fig. 108.

(84) **Galvani's Theory of Animal Electricity.**—Galvani supposed the existence of an *animal* electricity; a *nervous fluid* condensed in the interior of the muscle. The nerve, according to

his view, was only the conductor of the discharge of the two electricities contained in the muscle; and in one part of his *Commentary* he expressly says (Matteucci) that many of the contractions obtained with the metallic arc are *due to the arc itself*. To explain the action of the electrical current in producing muscular contractions, Galvani supposed that a change was determined in parts of the brain.

(85) **The Galvanoscopic Frog.**—To exhibit the experiments with the frog's legs generally, the legs of the frog are to be left attached to the spine by the crural nerves alone, and then a copper and a zinc wire being either twisted or soldered together at one end, the nerves are to be touched with one wire while the other is to be applied to the muscles of the leg. The arrangement is shown in Fig. 109. The frog is prepared for galvanoscopic experiments in the following manner:—A living animal is selected, two-thirds of the body just below the front paws are cut off, and the hind legs and pelvis with a piece of the spinal cord are preserved and skinned; then by intro-

Fig. 109.

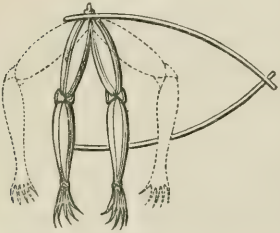
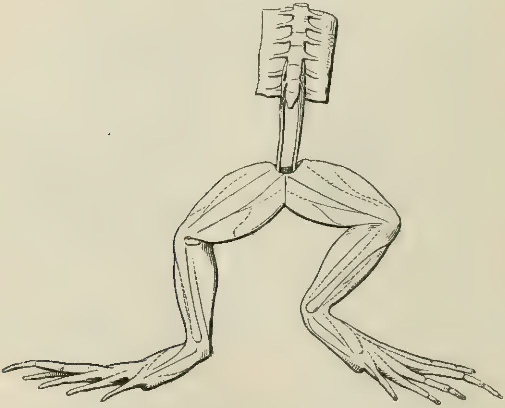


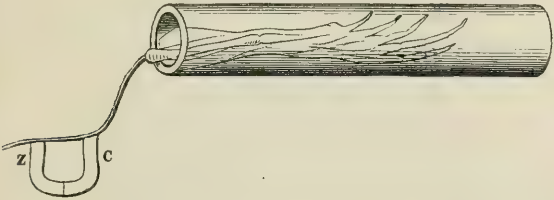
Fig. 110.



ducing the scissors between the lumbar nerves and the pelvis, and cutting the latter in two places, we obtain the frog prepared

after Galvani's plan. It is shown in Fig. 110. In order to employ the frog in the study of the electric current, the latter must be passed along the nervous filaments alone of the frog. For this purpose the frog, prepared as in Fig. 110, is cut in half; the bone and muscles of the thigh are removed, preserving its nerve untouched. In this manner we obtain a frog's leg, to which is attached a long nervous filament, composed of the lumbar portions of the pelvis and the crural portion of the thigh. We have only to introduce this leg into a tube of varnished glass to obtain an instrument very sensible to the passage of an electrical current. It is shown in Fig. 111.

Fig. 111.



To employ this kind of galvanoscope the glass tube is taken by the end opposite to that into which the leg of the frog has been introduced, and the nervous filament which is hanging outside the tube is made to touch the two points of the electro-motive element that we desire to study. When the nervous filament is traversed by an electric current, the leg is seen instantly to contract. Two pieces of moistened paper may be placed on the two points of the electro-motive element to avoid any irritation of the nerve by direct contact.

(86) **The Discovery of Volta.**—The first philosopher who repeated the experiments of Galvani was the celebrated Volta. Having verified the sensibility of the frog to electrical discharge, he applied himself to the experiments with the metallic arc; he ascertained that the contractions ensued simply on touching with the extremities of the metallic arc two points of the nervous filaments; he discovered that it was possible with the metallic arc to produce sometimes the sensation of light, sometimes that of taste, by applying it to the nerves of the eye or tongue; and from all his experiments he drew the conclusion that the muscular contractions were produced by the irritation of the nerves; that this irritation may produce sometimes *sensations*, sometimes *contractions*; and that, lastly, this irritation by the metallic arc was occasioned by the electric current developed by that arc.

Volta imagined that by the contact of any two *heterogeneous* con-

ductors, an action is developed by which the two bodies become charged with contrary electricities which may discharge themselves across a third not possessing the same action as the other two.

When it was objected to this hypothesis that a *homogeneous* metallic arc was sufficient to cause contractions in the frog, Volta replied that very small differences in the extremities of the arc were sufficient to produce an electric current, and that a very feeble current may irritate the nerve of a frog sufficiently to excite contractions. Thus he found that when one extremity of a metallic arc was heated and the other *not*, when one end was polished and the other *not*, sufficient *heterogeneity* was occasioned to excite a current. In vain did Galvani, Humboldt, Aldini, and others oppose to Volta the fact that without any metallic arc the frog may be made to contract, viz. by simply bending back the limb, and bringing it into contact with the lumbar nerves; Volta replied that it was only to generalise his theory of *electro-motive force*; that it was only necessary to say that the nerves and muscles of the frog act as the two metals of the arc, in order to explain the facts submitted by the partisans of Galvani.

Up to this time the development of electricity by the contact of heterogeneous metals was only a hypothesis of Volta's. It was in the month of August 1796 that he obtained, by means of the condenser, the first signs of electricity developed by the contact of two metals, and thus laid the foundation of his immortal discovery of *the pile*. The influence of this discovery over nearly all the sciences, and the rapidity with which it spread, caused all opposition on the part of Galvani to fall into oblivion, and for fifty years no one, save in a historical work, ventured to make any mention of *animal* electricity.

(87) **Matteucci's Researches: The Muscular Electric Current.**—Proof of the existence of an electric current circulating through the muscles of a living animal is obtained by introducing into a wound, formed in a muscle, the nerve of a prepared frog in such a manner that the extremity of the nerve shall touch the bottom of the wound, and another part the edge; the frog's leg instantly contracts. The muscular current may be detected in animals some time after death, but when it has once ceased it cannot again be renewed. It is found in *warm-* as well as in cold-blooded animals.

Matteucci constructed a *muscular pile* with which he succeeded in giving considerable deflection to the needle of the galvanometer. It was formed thus:—Five or six frogs were prepared and cut in half after Galvani's plan, great care being taken not to injure the muscle. The thighs were then cut in half, and so disposed that

each half-thigh should touch the following, the faces of each turning the same way, and the interior of one coming into contact with the exterior of the next; so that one of the extremities of the pile was formed of the interior of the muscle while the other extremity was formed of the surface. On completing the circuit through the galvanometer, a deviation of the needle was obtained amounting to 15°, 20°, 30°, 40°, 60°, according to the number of half-thighs; if the frogs were sufficiently active, a deviation of 2° and 4° was obtained with two elements; of 6° or 8° with four elements; of 10° or 12° with six elements, and so on, the direction of the current being from the interior of the muscle to the surface.

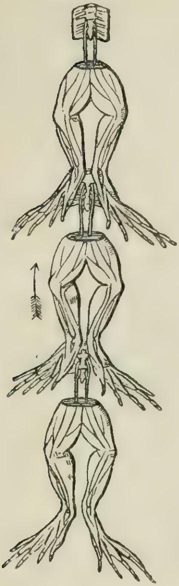
Similar experiments were made with slices cut from eels, tenches, and other fish; piles were also built up with slices of muscle cut from pigeons, chicken, oxen, sheep, &c., and ample evidence was obtained to prove that whenever the interior of the muscle of a recently killed animal is brought into conducting contact with the surface, an electrical current is established from the interior to the surface, the intensity varying with the animal, and increasing in proportion to the number of elements of which the pile is composed. It appears also from Matteucci's experiments, that the lower the animal in the scale of creation, the greater is the intensity and the longer the duration of the muscular current; thus from three piles, each of eight elements, one formed of muscle of rabbit, the second of muscle of pigeon, and the third of muscle of frogs, deviations of the galvanometer needle of 8°, 14°, and 22° were obtained. One hour after all signs of an electric current had disappeared from the *rabbit* pile, a deviation of 2° or 3° was obtained from the *pigeon* pile, and one of 8° or 10° from the *frog* pile; and even after the lapse of 24 hours, a deviation of 2° or 3° was obtained from the latter.

The muscular pile acts equally well in *atmospheric air*, in *oxygen*, in highly *rarefied* air, in *carbonic acid*, and in *hydrogen*; in the latter gas the needle of the galvanometer remains stationary for several hours. This nullity of the action of the different gases is considered by Matteucci to prove that the origin of the current is in the *muscle itself*; and that it is to the organisation of the muscle and to the chemical actions going on within its very structure that the current depends, he considers to be demonstrated by the fact that piles built up of *fibrine* separated from the blood of recently killed animals, produce no action on the galvanometer, and do not affect the galvanoscopic frog.

If a prepared frog be placed, as shown in Fig. 108, with its lumbar nerves plunged into one capsule filled with water, and with its legs placed in another, the circuit being completed through

the galvanometer, the instrument gives evidence of an electrical current passing from the feet towards the head of the animal. The effect is increased when several frogs are arranged on an insulated surface in the manner shown in Fig. 112, the nerve of each frog touching the legs of the following. Every time the circuit is completed the needle of the galvanometer moves and the limbs of the frogs contract. Matteucci has obtained signs of tension at the two extremities of his muscular piles; by the aid of the condenser he has also obtained electro-chemical decomposition by the current (*Comptes Rendus*, April 14, 1845).

Fig. 112.



If the spinal cord of a prepared frog be brought into contact with the muscles of the thigh, contraction takes place. By employing a galvanometer, and touching with one pole the leg, and with the other the thigh, Matteucci obtained indications of a current directed from the leg to the thigh, and from that by the nerve to the other thigh.

The general conclusions deduced by Matteucci from a long course of experiments are—

1. That the complete electro-motive element of the current of the frog is formed by one of its limbs—that is to say, of a leg, a thigh, its spinal nerve, and a piece of the spine.

2. That through each of the limbs of a frog there circulates the current of the other limb, whenever the two legs are made to touch.

3. That in experiments with the galvanometer we only get through the wire of the instrument, the current which results from the sum of those two portions of the current of the two limbs which do not discharge from limb to limb.

Then as to the parts of the frog which are necessary for the production of what Matteucci calls the *current proper*, and to the circumstances anatomical and physiological according to which its intensity varies, his experiments lead him to the following conclusions:—

1. That the *current proper* of the frog persists in its intensity and direction *without* the spinal cord, or the spinal and crural nerves, and even when

the animal is deprived of all the visible nervous filaments of the muscular mass of the thigh.

2. That the electro-motive element of this current is confined to the muscles of the leg and of the thigh organically united.

3. When there is left in the prepared frog the spinal cord, its nerves, and their ramifications through the muscles, these nervous parts act in the production of the current in the same manner as the muscular substance of the thigh.

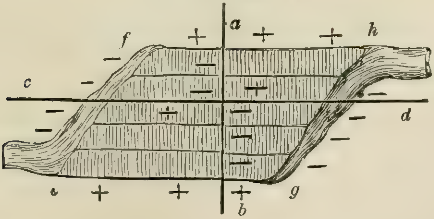
(88) **Du Bois Reymond's Researches.**—According to Du Bois Reymond (*Ann. der Physick und Chemie*, Bd. lviii.), electrical currents in all respects similar to the so-called *frog current* may be observed in the limb of any animal, whether cold- or warm-blooded; these currents in some limbs are directed upwards, as in the frog's leg; in others they are directed downwards; they are of different intensities in different limbs; but their intensity and direction are always the same in the same limb of different individuals of the same species.

The electro-motive action on which these currents depend does not, according to Du Bois Reymond, arise from the contact of heterogeneous tissues, as Volta supposed, for the different tissues, the nerves, muscles, and tendons, are in an electrical point of view quite homogeneous, but they are produced by the muscles.

If the undissected muscle of any animal be brought into the circuit longitudinally, it generally exhibits an electro-motive action, the direction of which depends on the position of the muscle on the ends of the galvanometer circuit.

By *longitudinal section* of a muscle, Du Bois Reymond understands a surface formed only by the *sides* of the fibres of the muscles considered as prisms. By *transverse section* of the muscle, he understands a surface formed by the *base* of the fibres of the muscles again considered as prisms. Both the transverse and the

Fig. 113.



longitudinal section may be either *artificial* or *natural* ones. Thus, in Fig. 113, a section through *a b* would be an artificial *transverse* one, and a section through *c d* an artificial *longitudinal* one.

A *natural transverse* section is at each end of the muscle formed by the ends of all the fibres, and hidden beneath a coating of tendinous tissue, which is in connection with the tendon itself, and, in an electrical point of view, plays the part of an indifferent conducting body (*e*, *f*, *g*, *h* in the figure). The *natural longitudinal* section of the muscle is that part of its external surface which extends from one natural transverse section to the other, being free from the tendinous coating, and exhibiting the red colour peculiar to muscles (*f*, *h*, *e*, *g* in the figure).

The law of the muscular current may be shortly expressed as follows :—

Any point of the natural or artificial longitudinal section of the muscle is *positive* in relation to any point of the natural or artificial transverse section.

It is easy, therefore, to understand why the muscular current in one instance appears to be an upward and in another a downward one, according as the under or the upper of the two transverse sections is made to touch one of the ends of the galvanometer wire, while the other end is applied to the longitudinal section of the muscle. Again, according to this law, every particle of a muscle, however minute, ought to produce a current in the same manner as the whole muscle, or as a larger piece of it. This consequence

Fig. 114.

is true, even as regards shreds of muscle consisting of only a few primary fibres. Fig. 114 represents the simplest case of the muscular current observed by Du Bois Reymond, the primary fibres being magnified 75 times.

The nerves, according to Du Bois Reymond's observations, are possessed of an electro-motive power which acts according to the same law as the muscles. Whilst still in organic connection with the muscles, and forming part of a circuit in which the muscles give rise to a current, the nerves simply play the part of an inactive conductor, provided their own current be prevented from entering the circuit.

In these delicate investigations it is necessary to guard against errors which might be introduced by the chemical action of the

saline solutions on the animal fluids. Matteucci employed, as the terminals of his galvanometer, plates of amalgamated zinc plunged into a neutral and saturated solution of sulphate of zinc, a liquid which, whilst it is an excellent conductor, does not act chemically on animal tissue. Du Bois Reymond's plan consisted in laying the muscle or nerve to be experimented upon between two pads composed of numerous layers of thin filtering paper saturated with the saline solution, and laid over the edges of the vessel in which the platinum terminals of the galvanometer were immersed, the animal substance not, however, being in direct contact with the moistened paper, but separated from it by a small piece of moistened bladder soaked in white of egg; this prevents any chemical action between the saline solution and the animal fluids, but does not stop the current. During the interval between the experiments the two pads are connected by a third, the object being to keep the circuit closed, and allow any polarisation of the platinum plates that may have taken place to neutralise itself.

(89) **Physiological Phenomena produced by a Muscle during Contraction.**—If the nervous filament attached to the leg of a prepared frog be made to touch the thighs of another frog, both insulated, and if the lumbar nerves of the latter be touched with a voltaic pair, contraction takes place not only in the muscles of the frog touched, but also in the leg of the other. The same thing happens if the lumbar nerves be irritated with a pointed instrument, contraction always taking place in the second frog, provided the contraction in the muscles of the first be sufficiently strong. The same experiment may be successfully performed with a rabbit. Matteucci found that, when the nerve of a prepared frog's leg was laid on the bared muscle of the thigh of a living rabbit, and the latter made to contract by a pile, contraction was at the same time produced in the leg of the frog. If a thin plate of an insulating substance be interposed between the muscle and the nerve, no contractions are excited in the second frog, but they are not prevented by a layer of thin unsized paper; the phenomenon cannot therefore be attributed to any mechanical action exercised on the leg by its nerves.

Becquerel supposed that at the instant the frog contracts there is an electrical discharge through the extremity of the nerve of the leg when this extremity is placed on the muscle, but Du Bois Reymond offered another explanation, founded on the following law:—

'When any point of the *longitudinal* section of a muscle is connected by a conductor with any point of the *transverse* section, an electric current is established which is directed in the muscle from the transverse to the longitudinal section; in other words, the real seats of the electro-motive action

are not only the separate muscles which compose the limbs, but the separate fibres which compose those muscles.'

If the transverse and longitudinal section of a muscle be in any way connected by the nerve of the prepared limb, a current will proceed through the said nerve from the latter section to the former. This current announces itself by the contraction of the muscle of the prepared limb on first making contact. The contractions cease when the current is fairly established in the nerve, and on breaking the circuit they are again observed. But it is not on the closing or the breaking of the circuit alone that the contractions are produced; every sudden fluctuation of the current traversing the nerve is accompanied by contractions. Applying this to the observation of Matteucci, we find that the current of the muscle against which the nerve of the prepared limb rests circulates through the said nerve. When the muscle is tetanised, this current is diminished at each convulsive effort, and its fluctuations are answered by corresponding contractions of the prepared limb. In reply to this, Matteucci denies that the nerve touches two portions of the muscle in the manner described by Du Bois Reymond, but the Paris academicians seem to have been satisfied with the explanation, for they came to the decision that the above fundamental fact furnishes a direct explanation of the *induced contraction* of Matteucci.

(90) **Action of the Electric Current on the Nerves of the Senses.**—The electrical current, when it acts on the nerves of the senses only, brings into play the special action appertaining to each of these nerves, a proof that the electric current acts merely as other stimulants.

It was Volta who first demonstrated the existence of a sensation of light when the electric current traverses any point of the optic nerve. The experiment is easily made by touching with a voltaic couple the eye or eyelid and the tongue. Whatever may be the intensity of the current, it is only the sensation of light that is perceived. If we reflect that this sensation may be produced by a very feeble current, and one certainly incapable of exciting a muscular contraction sufficiently strong to shake the eye, it must be admitted that the effect is really to be ascribed to the excitation of the optic nerve. An analogous phenomenon is produced when the current is made to act on the auditory nerves. Volta, on applying the two poles of a pile to his two ears, experienced a *hissing* or *jerking* noise, which continued all the time the circuit remained closed. According to Ritter, the sensation is only experienced at the commencement of the current, and the noise is sharper at the negative pole.

Again, in the experiment of Sulzer, a taste is experienced when the tongue is traversed by an electrical current. This taste is sourish when a plate of zinc is placed at the base of the organ and a plate of silver on the surface, the two plates being brought into contact; by reversing the position of the plates the taste becomes alkaline, but this feeble intensity current cannot be supposed to decompose the salts contained in the saliva. A similar sensation was experienced by Volta by taking in his hand a goblet of pewter filled with a moderately alkaline solution, and bringing the *base* of the tongue into contact with the liquid. The taste was *sour*, which excludes the idea that it was occasioned by the contact of the alkaline liquor with the tongue. It seems evident, therefore, that the taste excited by the electric current must be owing to the special excitation of the gustatory nerves. In general, then, the effect of a current acting on the nerves of the senses is to awaken the special function of these nerves.

The passage of an electric current through the cardiac and *splanchnique* nerves of a living or recently-killed animal increases or arouses the motion proper of the heart and intestines, but, what is very remarkable, the phenomenon due to the passage of the current, instead of commencing at the very instant that the circuit is closed, only begins after a certain time, and continues for some time after the current has ceased. It must not be forgotten that all other stimulating agents, viz. alkalies, mechanical irritations, or heat, applied to the ganglion nerves, act in the same manner as the electrical current.

(91) **Production of an Electric Current by Muscular Contraction.**—If it be granted that the muscular current is developed in the muscle itself, it can scarcely be doubted that it is in a state of circulation during the life of the animal. On connecting the transverse and longitudinal sections of a muscle, an electrical current appears; but such a connection exists naturally in the body, and hence the influence that such currents are perpetually present is a fair one, the current indicated by the galvanometer being in fact but one of the branches of the pre-existing current. Du Bois Reymond placed a live frog with its two legs dipping into two vessels filled with salt and water, and connected with either extremity of a galvanometer. Now it was long ago shown by Nobili that a current exists in the frog directed from the foot upwards, but in the present case there are two such currents, one at each foot, which meet at the junction of the limbs, annul each other, and consequently produce no effect on the galvanometer. But suppose one of these currents to be enfeebled, while the other retains its full strength; the result will be that the

excess of the latter current should produce a deflection. Du Bois Reymond, accordingly, severed the *ischiatic* nerve of one of the frog's legs, and thus deprived the limb of all power of motion; he then poisoned it with strychnia—strong convulsions followed; the uninjured limb contracted violently, its muscular current was thereby diminished, and the current of the other limb was immediately exhibited by the galvanometer.

Du Bois Reymond then tried the experiment on himself. He placed the first finger of his right hand in one vessel, and the corresponding finger of the left hand in the other; but instead of cutting his nerves, as in the case of the frog, he suffered the left arm to remain at rest, and, contracting the other forcibly, produced a deflection of the needle; when the left arm was contracted, and the right one suffered to remain at rest, the needle was deflected in the opposite direction. The current always proceeded *from the hand of the contracted arm to the shoulder*; but remembering the fact that it is the *excess* of the current of the motionless arm which is here observed, the inference is that in the normal state of the arm the direction of the current is *from the shoulder to the hand.*

(92) **Electric Fishes.**—*The Torpedo.*—There are some remarkable instances of the generation of electricity in living animals, to whom the power seems principally to be given as a means of defence. Of these animals the *raia torpedo* appears to have been noticed at a very early period, since we find a description of its properties in the writings of Pliny, Appian, and others. It inhabits the Mediterranean and North Seas; its weight, when fully grown, is about eighteen or twenty pounds.

Fig. 115.

Fig. 115 is a representation of a female torpedo, the skin B having been flayed from the under surface of the fish to show the *electric organs* A. The mouth, having the form of a crescent, is shown at *d*; the branchial apertures, five in number, at E; *g g g* the place of the anterior transverse cartilages; *h h* the exterior margin of the great lateral fin; *i* its inner margin on

the confines of the electrical organ; l the abdomen; m m the place of the posterior transverse cartilage, which is single, united with the spine, and sustains the smaller lateral fins n n on each side; o is the anus, and p the fin of the tail. Each electrical organ is about 5 inches long and about 3 inches broad at the anterior end and half an inch at the posterior extremity. Each organ consists wholly of perpendicular columns reaching from the upper to the under surface of the body, and varying in their lengths according to the thickness of the parts of the body where they are placed. The longest column is about $1\frac{1}{2}$ inch, the shortest about $\frac{1}{4}$ of an inch, and their diameter about $\frac{2}{10}$ of an inch. The figures of the columns are irregular hexagons or pentagons, and sometimes have the appearance of being quadrangular or cylindrical. The number of columns in the fish examined by John Hunter was 470 in each organ; but in a very large fish, $4\frac{1}{2}$ feet long and weighing 73 pounds, the number was 1,182 in each organ. The number of partitions in a column one inch long was 150.

The torpedo must be irritated to cause it to give a shock, in the delivery of which it moves its pectoral fins convulsively; the shock is felt on touching the fish with a single finger, and it can give a long series of shocks with great rapidity. When the torpedo is placed on a metallic plate, so that the plate touches the inferior surface of the organs, the hand that supports the plate never feels any shock, though another insulated person may excite the animal and the convulsive movement of the pectoral fins may denote the strongest and most reiterated discharges; direct contact with the electrical organs of the fish is indispensably necessary for the reception of the shock, but the torpedo has not the power of directing its electrical discharge through any particular object.

By passing the discharge from a torpedo through a spiral of copper wire enclosing a steel needle, the needle becomes magnetised in such a manner as to show the direction of the current to be from the back to the under part of the belly. Heating and chemical effects have likewise been obtained. According to the experiments of Matteucci—1. All the dorsal parts of the electrical organ are *positive* to all the *ventral* parts. 2. Those points of the organ on the dorsal face which are above the nerves which penetrate this organ are *positive* relatively to other points of the same dorsal face. 3. Those points of the organ on the ventral face are negative relatively to other points of the same ventral face.

The Gymnotus.—This electrical fish is a native of the warmer regions of America and Africa. There are several species of the gymnotus, but only one is electrical. In general aspect, it very much resembles an eel—the body is smooth, and without scales (a peculiarity of all electrical fishes). The electric organs consist of alternations of different substances, and are most abundantly supplied by nerves; their too frequent use is succeeded by debility and death. The electric organs may be removed without injury to the fish.

Fig. 116 is a copy of Hunter's engraving of the gymnotus, and Fig. 117 is a correct representation of a fine specimen which was for some time in the possession of the proprietors of the Royal Polytechnic Institution. In Hunter's engraving the skin is removed to show the structure of the fish; *a* is the lower surface of the head; *c* the cavity of the belly; *b* the anus; *e* the back where the skin remains; *g g* the fin along the lower edge of the fish; *e e* the lateral muscles of this fin removed and laid back with the skin to expose the small organs; *l* part of the muscle left in its place; *f f* the large electrical organ; *h h* the small electrical organs; *m m m* the substance which separates the two organs; and *n* the place where the substance is removed. These organs form more than one-third of the whole fish. The two electrical organs are separated at the upper part by the muscles of the back, at the lower part by the middle partition, and by the air-bag at the middle part.

Fig. 116.

Fig. 117.

The electrical organs consist of two parts, viz. flat partitions or septa, and thin plates or membranes intersecting them transversely. The septa are thin parallel membranes stretching in the direction of the fish's length, and as broad as the semi-diameter of the animal's body. They vary in length, some of them being as long as the whole body. The very thin plates which intersect the septa have their breadth equal to the distance between any two septa. There is a regular series of these plates from one end of any two septa to the other end, 240 of them occupying a single inch.

The electric organ of the gymnotus depends entirely on its will. It does not keep its organs always charged, and it can direct its action towards the point where it feels itself most strongly irritated. When two persons hold hands, and one touches the fish with his free hand, the shock is commonly felt by both at once.

Occasionally, however, in the most severe shocks, the person who comes into immediate contact with the fish alone receives it.

A fine specimen of this remarkable fish was for some time in possession of the proprietors of the late Gallery of Practical Science in Adelaide Street, and was made the subject of some interesting experiments by Faraday (*Ex. Researches*, 15th series, 1838). This fish was forty inches long. It remained in a healthy and vigorous condition till March 1842, when it died from the effects of a rupture of a blood-vessel.

1. *The Shock.*—This was very powerful when one hand was placed on the body near the head, and the other near the tail. It was like that of a large Leyden battery charged to a low degree; and great as was the force of a single discharge, the fish was able to give a double and even a triple shock with scarcely a sensible interval of time. From some comparative experiments, Faraday thought it may be concluded that a single medium discharge of the fish was at least equal to that of a Leyden battery of fifteen jars, containing 3,500 square inches of glass coated on both sides, and charged to the highest degree.

2. *The Spark.*—Through the upper cap of a glass globe a copper wire was passed, a slip of gold leaf being attached to its extremity; a similar wire terminating in a brass ball within the globe was passed through the lower cap. The gold leaf and brass ball were brought into all but actual contact; the fish being provoked to discharge through the wires, the gold leaf was attracted to the ball, and a *spark* passed.

3. *Chemical Decomposition.*—Polar decomposition of iodine of potassium was obtained by moistening three or four folds of paper in the solution, and placing them between a platinum plate, and the end of a platinum wire connected respectively with two saddle conductors grasping the body of the fish. The middle of the fish was found to be *negative* to the *anterior* parts and *positive* to parts towards the tail.

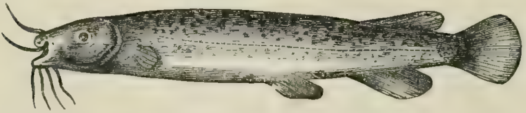
4. *Magnetic Effects.*—By causing the fish to send powerful discharges through an instrument of no great delicacy, a deflection of the needle amounting to 30° was produced; the deflection was constantly in a given direction, the electric current being always from the anterior parts of the animal through the galvanometer wire to the posterior parts. When a little helix, containing twenty-two feet of silked wire wound on a quill, was put into the circuit, and an annealed steel needle placed in the helix, the needle became a magnet, and the direction of its polarity in every case indicated a current from the *anterior* to the *posterior* parts of the gymnotus through the conductors used.

When a number of persons all dip their hands at the same time into the water in the vessel in which the gymnotus is confined, they *all* receive a shock of greater or less intensity when the fish discharges, proving that all the conducting matter round the fish is filled at the moment with circulating electric power resembling generally in disposition the magnetic curves of a magnet. The gymnotus feeds on other fish, which it kills by giving them a shock; this it does by forming a coil round the fish, so that it should re-

present a diameter across it. Living, as the gymnotus does, in the midst of such a good conductor as water, it seems at first surprising that it can sensibly electrify anything; but in fact it is the very conducting power of the water which favours and increases the shock by moistening the skin of the animal through which the gymnotus discharges its battery.

The Silurus Electricus.—This fish is shown in Fig. 118. It is found in the Senegal, the Niger, and the Nile. It is about twenty

Fig. 118.



inches long. The shock is distinctly felt when it is laid on one hand, and touched by a metallic rod held in the other. Its electrical organs are much less complicated than those of other electrical fishes. Other known electrical fishes are the *tetraodon electricus*, found in the Canary Islands, and the *trichiarus electricus*, which inhabits the Indian seas; several others have been met with, but not hitherto actually described.

(93) **Electricity of Plants.**—The following conclusions were arrived at by Wartmann (*Bibliothèque Universelle de Genève*, Dec. 1850), after an investigation continued for two years:—

1. Electric currents are to be detected in all parts of vegetables but those furnished with isolating substances, old bark, &c. &c.

2. These currents occur at all times and seasons, and even when the portion examined is separated from the body of the plant, as long as it continues moist.

3. In the roots, stems, branches, petioles, and peduncles there exists a central descending and a peripherical ascending current; Wartmann calls them *axial* currents.

4. Lateral currents may be detected passing from the layers of the stem where he liber and alburnum touch to the surrounding parts.

5. In the leaf the current passes from the lamina to the nerves, as well as to the central parts of the petiole and stalk.

6. In the flowers the currents are feeble. They are very marked in the succulent fruits, and in some kinds of grain; the currents from fruits proceeding in most cases from the superficial parts to the adjacent organs. The strength of the currents depends on the season; they are greatest in the spring, when the plant is bathed in sap.

7. Currents can also be detected proceeding from the plant to the soil, which is thus positive with relation to it, and currents are also manifested when two distinct plants are placed in the circuit of the rheometer.

These results were confirmed by Becquerel (*Comptes Rendus*, Nov. 4, 1850). He ascertained particularly the determination

of electrical currents from the pith of the wood to the bark, which shows that the earth in the act of vegetation continually acquires an excess of positive electricity; and the parenchyma of the bark and a part of the wood an excess of negative electricity, which is transmitted to the air by means of the vapour of exhaled water; and the opposite electrical states of vegetables and the earth give reason to think that, from the enormous vegetation in some parts of the globe, they must exert some influence on the electric phenomena of the atmosphere.

Flashes of light have been seen to be emitted from many flowers, principally *orange*-coloured flowers, soon after sunset on sultry days; this phenomena was diligently studied by Zawadski; he noticed that it occurred most frequently in the months of July and August, and he observed that the same flower discharged a number of flashes in succession.

Pouillet made the following experiment, from which he arrived at the conclusion that a considerable portion of the electricity with which the atmosphere is charged is derived from the gaseous fluids given out by plants during the process of vegetation:—

On a table varnished with gum lac, he arranged in two rows beside each other twelve glass capsules, each about eight inches in diameter, and coated externally for two inches round the lips with a film of lac varnish. They were filled with vegetable mould, and made to communicate with each other by metallic wires, which passed from the inside of one to the inside in the next, going over the edges of the capsules. Thus the inside of the twelve capsules and the soil which they contained formed only a single conducting body. One of the capsules was placed in communication with the upper plate of a condenser by means of a brass wire, while, at the same time, the under plate was in communication with the ground.

Things being in this situation, and the weather being very dry, a quantity of corn was sown in the soil contained in the capsules, and the effects were watched. The laboratory was kept closed, and neither fire, nor light, nor any electrified body, was introduced into it. During the first two days the grain swelled, and the plumulæ issued out about the length of a line, but did not make their appearance above the surface of the earth. But on the third day the blades appeared above the surface, and began to incline towards the window, which was not provided with shutters. The condenser was now charged with *positive* electricity; consequently the carbonic acid which is disengaged during the germination of the seed is charged with positive electricity, and is therefore in precisely the same state as the carbonic acid formed by combustion. This experiment was repeated several times with success. But the electricity cannot be recognised unless the weather is exceedingly dry, or unless the apartment is artificially dried by introducing substances which have the property of absorbing moisture.

Pouillet inferred from his experiments that a surface of 1,000 square feet would give out sufficient electricity to charge a powerful battery.

CHAPTER VIII.

VOLTAIC ELECTRICITY.

Volta's Fundamental Experiment—The 'Pile'—The Dry Pile—The Contact and Chemical Theories of the Pile—Simple and Compound Voltaic Batteries—The Water Battery—Polarisation—Secondary Batteries—The Gas Battery.

(94) **Volta's Fundamental Experiment.**—Two polished metallic discs, one of copper and the other of zinc, about three inches in diameter, and each provided with an insulating handle, are brought into contact, holding them by their handles; they are then separated, especially avoiding friction, and brought successively into contact with the collecting plate of a condensing electroscope (Fig. 19, p. 20); the zinc plate is found to be slightly charged with *positive* and the copper plate with *negative* electricity. These effects (which, though feeble, are, when carefully performed, decisive) were ascribed by Volta to a peculiar electromotive force, under which the metals by simple contact tend to assume opposite electrical states; but it has been shown by Grove (*Elect. Mag.*, vol. i. 57) that Volta's experiment is equally successful if *contact* between the metals is prevented by the interposition of a circle of card, and he conceives the action between the discs to be somewhat similar to that which occasions a coin, when allowed to remain for some time on a polished plate, to leave behind it on the metal a faint picture, viz. to a radiation between the metals, on account of difference of temperature, whereby a chemical disturbance takes place. Gassiot has also proved that decided signs of electrical tension may be obtained without any contact, metallic or otherwise, between the plates. His experiment is thus described (*Phil. Mag.*, Oct. 1844):—

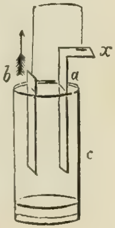
Two plates, one of copper and the other of zinc, each four inches in diameter, were attached each to an insulated pillar of a micrometer electrometer; the plates were carefully approximated to about $\frac{1}{100}$ of an inch. When thus adjusted, a copper wire was attached to each of the plates, and also to the discs of the electroscope, which were fixed at about $\frac{1}{8}$ of an

inch apart; the leaf of the electroscope was raised so as to allow it to swing clear of the two discs, and, when not excited, to remain equidistant from each. Thus arranged, the apparatus is ready for experiment. With one hand the experimenter holds a Zamboni's pile, so as to have one of its terminals within about one inch of the cap of the electroscope, and with the other hand he separates the plates; immediately on separation the terminal of the pile is brought into contact with the cap of the electroscope, when the leaf is attracted as follows:—If touched by the *negative* terminal of the pile, the leaf of the electroscope will be attracted towards the disc in connection with the *zinc* plate, but if by the *positive* terminal, the leaf will move towards the disc in connection with the *copper* plate, which are precisely the same results as follow the separation after *actual* contact.

By the following arrangement a voltaic current of sufficient power to decompose *iodide of potassium* was produced by Faraday without the contact of dissimilar metals:—

A plate of zinc, *a* (Fig. 119), was cleaned and bent in the middle to a right angle; a piece of platinum about three inches long and half an inch wide, *b*, was fastened to a platinum wire, and the latter bent twice at right angles. These two pieces of metal were arranged as shown in the figure; at *x* a piece of folded bibulous paper, moistened in a solution of iodide of potassium, was placed on the zinc, and was pressed upon by the end of the platinum wire; when, under these circumstances, the plates were immersed in diluted nitric and sulphuric acids, or even in solution of caustic potash, contained in the vessel *c*, there was an immediate effect at *x*, the iodide being decomposed, and iodine appearing at the anode, that is, against the end of the platinum wire. As long as the lower ends of the plates remained in the acid, the electric current flowed, and the decomposition proceeded at *x*. On removing the end of the wire from place to place on the paper, the effect was evidently very powerful; and on placing a piece of turmeric paper between the white paper and the zinc, both papers being moistened with a solution of iodide of potassium, alkali was evolved at the *cathode* against the zinc in proportion to the evolution of iodine at the *anode*; the presence of an electric current was likewise shown by the galvanometer.

Fig. 119.



Metallic contact, according to Faraday, favours the passage of the current by diminishing the opposing affinities. When an amalgamated zinc plate is dipped into dilute sulphuric acid, the force of chemical affinity exerted between the metal and the fluid is not sufficiently powerful to cause sensible action at the surfaces of contact, and occasion the decomposition of water by the oxidation of the metal, though it *is* sufficient to produce such a condition of electricity as would produce a current if there were a path open for it, and that current would complete the conditions necessary for the decomposition of water. Now, when the zinc is

touched by a piece of platinum, the path required for the electricity is opened, and it is evident that this must be far more effectual than when the two metals are connected through the medium of the electrolyte; because a *contrary and opposing action* to that which is influential in the dilute sulphuric acid is then introduced, or at any rate the affinity of the component parts of the electrolyte has to be overcome, since it cannot conduct *without decomposition*, and this decomposition reacts upon, and sometimes neutralises, the forces which tend to produce the current.

The views of Volta have been supported by many profound electricians, including Pfaff, Marianini, Fechter, Zamboni, and Matteucci, but the most powerful mass of evidence is in favour of the theory that ascribes the source of power to *chemical action*, and this theory has been adopted and maintained by Fabroni, Wollaston, Oersted, Becquerel, De la Rive, Schönbein, Faraday, Grove, and numerous other distinguished philosophers.

By Davy (*Phil. Trans.* 1826) the electric state of the pile was considered as due partly to the contact of the opposed metals, and partly to the chemical action excited on them by the liquid.

'Chemical and electrical attractions,' he says, 'are produced by the same cause, acting in one case on *particles* and in the other on *masses* of matter, and the same property, under different modifications, is the cause of all the phenomena exhibited by different voltaic combinations.'

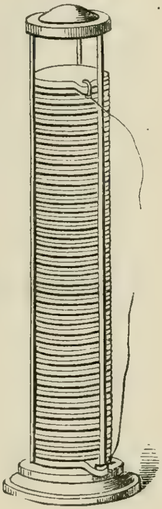
In Volta's fundamental experiment the zinc plate is supposed by him to take electricity from the copper plate, the zinc plate becoming feebly *positive*, and the copper plate feebly *negative*. Professor Robison endeavoured to increase the effect by associating a series of plates of copper and zinc, one pair immediately following the other. The desired effect was not, however, attained, as, indeed, Volta's theory would have predicted, for as in such an arrangement each copper plate is necessarily between two zinc plates, and each zinc plate between two copper plates, according to that theory *electromotion* would tend from the copper to the zinc upon both sides of the latter, and the forces would destroy one another. The same thing would occur conversely with both surfaces of the copper, so that, however numerous the series, the effect cannot exceed that produced by a single pair. This explanation immediately occurred to Volta, and the brilliant idea suggested itself that, if he were to interpose between each pair of copper and zinc plates a moist or second-class conductor, the latter would have the effect of promoting the circulation of the disturbed electricity, its own power of producing electromotion by contact with the metals being extremely small when compared to the energy of the electromotive force called into existence by the contact of

the dry or second-class metallic conductors. In accordance with this hypothesis he built up his 'pile.'

The original form of Volta's pile is shown in Fig. 120.

It consists of a series of silver and zinc or of copper and zinc plates, arranged one above another, with moistened flannel or pasteboard between each pair. A series of thirty or forty alternations of plates four inches square will cause the gold-leaf electroscope to diverge, the zinc end with *positive* and the silver end with *negative* electricity; a shock will also be felt on touching the extreme plates with the fingers moistened with water; a small spark will be seen on bringing the extreme wires into contact, and water may be decomposed. These latter effects are much increased when the flannel or pasteboard is moistened with *salt* and water, the *quantity* of electricity set in motion by the chemical action of the saline liquid being materially increased, but the gold leaves of the electroscope will not exhibit a greater divergence when salt water is used, this effect depending on the *intensity* of the electricity, which is not materially augmented by the chemical action.

Fig. 120.



(95) **The Dry Pile.**—An electric pile was invented by De Luc, from which much useful information respecting the direction of the current in these cases of excitation may be derived.

This instrument consists of a number of alternations of two metals, with discs of paper interposed; the elements may be circular discs of thin paper, covered on one side with gold or silver leaf about one inch in diameter, and similar-sized pieces of thin zinc foil, so arranged that the order of succession shall be preserved throughout, viz. zinc, silver, paper; zinc, silver, paper, &c. About five hundred pairs of such discs, enclosed in a perfectly dry glass tube, terminated at each end with a brass cap, and screw to press the plates tight together, will produce an active column. The late Mr. Singer constructed a dry pile of twenty thousand series of zinc, silver, and double discs of writing-paper; it was capable of diverging the pith-ball electroscope, and by connecting one extremity of the series with a fine iron wire, and bringing the end of the wire near the other extremity, a slight layer of varnish being interposed, *a succession of bright stars could be produced*, especially when the point of the wire was drawn lightly over the surface. A very thin glass jar, containing fifty square inches of coated sur-

face, charged by ten minutes' contact with the column, had power to fuse one inch of platinum wire $\frac{1}{5000}$ of an inch in diameter. It gave a disagreeable shock, felt distinctly at the elbows and shoulders, and by some individuals across the breast. The charge from this jar would perforate thick drawing-paper. The pile did not possess the slightest chemical action, for saline compounds tinged with the most delicate vegetable colours underwent no change, even when exposed for some days to its action.

On examining the electrical state of the dry electric column, it is found to resemble that of a conductor under induction; in the centre it is *neutral*, but the ends are in opposite electrical states; and if one extremity be connected with the earth, the electricity of the opposite end becomes proportionately increased: the zinc extremity is *positive*, and the silver or gold extremity is *negative*: as may be proved by laying the column on the caps of two gold-leaf electroscopes in the manner shown in Fig. 121; the leaves will

Fig. 121.

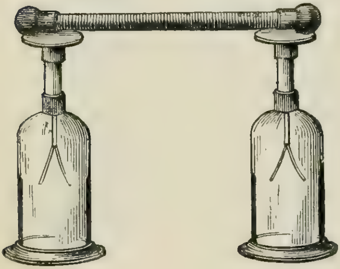
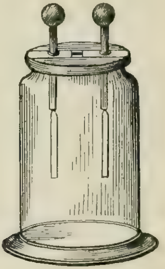


Fig. 122.



diverge with opposite electricities. If a communication be made between the instruments by means of a metallic wire, the divergence of the leaves will cease, but will be again renewed when such communication is broken. It is better to employ, in these experiments, an electroscope in which the gold leaves are suspended singly, as shown in Fig. 122, and so arranged as to admit of their being brought nearer to or carried farther from each other. If in such an instrument the leaves are adjusted at a proper distance from each other, and the wire from which one is suspended be connected with the zinc end of the pile, and the wire from which the other is suspended be connected with the silver or gold end, a kind of perpetual motion will be kept up between the leaves; for, being oppositely excited, they will attract each other; and having

by contact neutralised each other, they will separate for a moment and again attract and separate as before. If both silver and zinc ends of two columns are connected with the two gold leaves, a continued repulsion will be kept up between the leaves, they being then similarly electrified.

A variety of amusing experiments may be made with De Luc's dry column. Thus, a small clapper may be kept constantly vibrating between two bells. With a series of twelve hundred groups, arranged by Mr. Singer, a perpetual ringing was kept up during fourteen months. De Luc had a pendulum which constantly vibrated between two bells for more than two years. With a pile of 10,000 series, constructed after the modification by Zamboni, in which the discs consisted of paper, on one side of which finely laminated zinc was pasted, and on the other finely powdered black oxide of manganese, Mr. Gassiot charged a Leyden battery to a considerable degree of intensity, and obtained direct sparks $\frac{3}{50}$ of an inch in length. He ultimately succeeded in obtaining chemical decomposition of a solution of iodide of potassium, the iodine appearing at the end composed of black oxide of manganese.

The source of power in the 'dry pile' is referred by those who uphold the theory of Volta to the contact of the metals; the opponents of that hypothesis trace it to the action of the small portion of moisture which is contained in the paper upon the oxidisable metal, viz. the zinc. It is certain that a degree of moisture is indispensable to the action of the instrument; for the electricity disappears altogether when the paper discs have lost their humidity by spontaneous evaporation, and the zinc becomes slowly corroded. Its charge is altogether one of intensity, and after discharge an interval of time is required for a renewal. It is not improbable that the state of the atmosphere is in some way connected with the phenomenon, for the motion of the pendulum is subject to much occasional irregularity. M. de Luc and Mr. Hausman both observed that the action of the column was increased when the sun shone on it; but they conceived that the effect was not due to the heat of the sun's rays, because it was found that an instrument put together, after the parts had been thoroughly dried by the fire, had no power whatever, but that it became efficacious after it had been taken to pieces, and its materials had remained all night exposed to the air, from which the paper imbibed moisture. Mr. Singer, however, remarked that the power of the column is increased by a moderate heat, as his apparatus vibrated more strongly in summer than in winter, and the electrical indications were stronger when there was a fire in the room.

Care should be taken not to allow the ends of the column to remain for any length of time in contact with a conducting body; for, after such continued communication, a loss of power will be

perceived. When, therefore, the instrument is laid by, it should be insulated; and if it had previously nearly lost its action, it will usually recover it after a rest of a few days. The application, by Bohnenberger, of the dry pile to the gold-leaf electroscope has already been alluded to (41, 6).

(96) **Insufficiency of the Contact Theory.**—At the close of an elaborate and exhaustive experimental examination of the question, 'What is the source of power in the voltaic pile?' Faraday sums up thus (*Ex. Research.*, series xvii.):—

'The contact theory assumes, in fact, that a force which is able to overcome powerful resistance, as, for instance, that of the conductor, good or bad, through which the current passes, and that again of the electrolytic action, where bodies are decomposed by it, can arise out of *nothing*; that without any change in the acting matter, or the consumption of any generating force, a current can be produced which shall go on for ever against a constant resistance, or only be stopped, as in the voltaic trough, by the ruins which its exertion has heaped up in its own course. This would indeed be a *creation of power*, and is like no other force in nature. We have many processes by which the form of the power may be so changed that an apparent *conversion* of one into another takes place; but in no case is there a pure creation of force; a production of power without the corresponding exhaustion of something to supply it.

'The *chemical* theory sets out with a power, the existence of which is pre-proved, and then follows its variations, rarely assuming anything which is not supported by some corresponding simple chemical fact.

'The *contact* theory sets out with an assumption, to which it adds others as the cases require, until at last the contact force, instead of being the firm unchangeable thing at first supposed by Volta, is as variable as chemical force itself.

'Were it otherwise, and were the contact theory true, then, as it appears to me, the equality of cause and effect must be denied. Then would "perpetual motion" also be true; and it would not be at all difficult upon the first given case of an electric current, by contact alone, to produce an electro-magnetic arrangement which, as to principle, would go on producing mechanical effects for ever.'

Again, speaking of the voltaic theory of contact, Dr. Roget, in his *Treatise on Galvanism*, says (§ 113):—

'Were any further reasoning necessary to overthrow it, a forcible argument might be drawn from the following consideration:—If there could exist a power having the property ascribed to it by the hypothesis—namely, that of giving continual impulse to a fluid in one constant direction, without being exhausted by its own action—it would differ essentially from all the other known powers in nature. All the powers and sources of motion, with the operation of which we are acquainted, when producing their peculiar effects, are expended in the same proportion as those effects are produced; and hence arises the impossibility of obtaining by their agency a perpetual effect, or, in other words, a perpetual motion. But the electromotive force ascribed by Volta to the metals when in contact is a force which, as long as

a free course is allowed to the electricity it sets in motion, is never expended, and continues to be excited with undiminished power in the production of a never-ceasing effect. Against the truth of such a supposition the probabilities are all but infinite.'

Lastly, Sir William Snow Harris, in reviewing the two theories of the voltaic pile, expresses his opinion of the contact theory in the following terms (*Rudimentary Treatise on Galvanism*, p. 52):—

'On reviewing the respective merits of the contact and chemical theories of the source of power in the voltaic pile, we find the facts in support of the latter so overwhelming in every sense that it is next to impossible to resist the conclusion that chemical action is really the mainspring of the whole machine. We find, for example, that chemical action does give rise to evolution of electricity; that the current force is entirely dependent on it; that, when the chemical action diminishes or ceases, the current also diminishes or ceases; when the chemical action changes, the current changes; when there is no chemical action, there is no current; no case has ever arisen of electrical current in the voltaic apparatus without chemical action, and there is every ground for supposing that the force termed chemical affinity is identical with electrical force.

'On the other hand, the *contact* theory is embarrassed by anomalies and improbabilities in the nature of things. It assumes that a current is called into action and maintained by metallic contact alone; here we must assume the force of contact to be so balanced as to produce in any voltaic circle an effect equal to zero, and whilst the metallic substances in contact remain in every sense unchanged as regards their particles, they are supposed actually to discharge into each other; if any change of state or condition in their constituent particles were admitted, it would then become a *chemical* theory. The two metals also, by this hypothesis, are in opposite electrical states, the one being positive, the other negative, which states become at once destroyed by the intervening fluid, and recommence;—but how? The whole effect of the apparatus is by the theory a disturbance and reproduction of electrical equilibrium; it in no way supplies an explanation of the production and evolution of electricity. The force, which is supposed competent to produce a change of electrical state in metals in respect to each other, is yet incompetent by the hypothesis to maintain the new state induced; and without any consumption whatever of the generating force, we are obliged to assume the production of a current, continually flowing on, against a constant resistance; this is not in the nature of things of which we have the least experience. There is no instance in nature of a production of power without a corresponding exhaustion of the source of power.'

(97) **Simple Voltaic Circles.**—Assuming, then, that the electricity set in motion by the contact of the copper and zinc plates in Volta's fundamental experiment is the result of slight chemical action, it is easy to understand that increase of chemical action should give rise to an augmentation of electrical force. If we take two plates of different metals—platinum and zinc, for example—and immerse them in pure water, touching each other, as in Fig. 123, a *galvanic circle* will be formed; the water will be slowly decomposed,

its oxygen becoming fixed on the zinc, the oxidisable metal, and at the same time a current of electricity will be transmitted through the liquid to the platinum, on the surface of which the other constituent of the water, viz. hydrogen, will make its appearance in the form of minute gas bubbles; the electrical current passes back again to the zinc plate at its point of contact with the platinum, and thus a continued current is kept up. The moment the circuit is broken by separating the metals, the current ceases, but is renewed on making them again touch. It is not indispensable that the two plates should be brought into immediate contact, as in Fig. 123; they may be metallically united by wires, which may be of any length provided they are continuous throughout, and are brought into contact at their ends, as shown in Fig. 124. The effect with

Fig. 123.

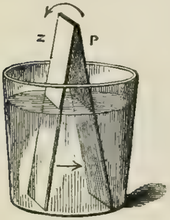
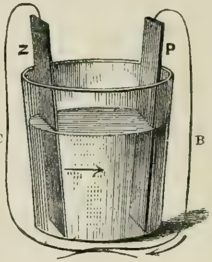


Fig. 124.



pure water is feeble, and after some time the current nearly ceases in consequence of the surface of the zinc becoming coated with oxide; if, however, a little sulphuric or hydrochloric acid be added to the water, the effect is greatly increased, because, in the first place, we make the liquid a better conductor of electricity; and, secondly, and chiefly, because the oxide of zinc is removed from the surface of the metal as fast as it is formed, being dissolved by the acid, a new and clean surface is thus continually exposed, and an increased facility for the decomposition of water is afforded. The force originates with the oxidation of the zinc, and passes in the direction of the arrow through the liquid to the platinum, and thence back by the wires B C to the zinc; sulphate, or chloride of zinc, is formed in the liquid, but the formation of either of these salts has little, if anything, to do with the development of the electrical current, chemical *decomposition* being, according to the chemical theory, absolutely necessary for the development of current electricity.

To prove that the wire connecting the platinum and zinc plates is conducting a current of electricity, we have only to place a nicely-balanced magnetic needle above or below it, and we shall find that the needle will deviate from the magnetic meridian in obedience to laws which will be described hereafter (*Electro-magnetism*) ; but how are we to account for the appearance of the bubbles of hydrogen gas on the surface of the platinum plate?

If the zinc plate be amalgamated by dipping it into dilute sulphuric acid, and then rubbing it over with mercury, it will be found that dilute sulphuric acid has little or no action upon it while unconnected with the platinum ; the moment, however, that metallic communication is established between the two plates, either in or out of the liquid, torrents of bubbles will rise from the latter metal, as if it were undergoing violent chemical action, while the zinc (the metal which is *really* being acted upon chemically) is dissolved tranquilly, and without any visible commotion. It is evident that this phenomenon cannot be explained on chemical grounds *alone*; the transference of the hydrogen is to be considered as taking place by the propagation of a decomposition through a chain of particles extending from the zinc to the platinum. Let the exciting liquid be supposed to be dilute sulphuric acid (HSO_4); as soon as metallic communication is established between the two plates, the particle of HSO_4 in contact with the zinc undergoes decomposition, the SO_4 combining with the zinc to form the compound $ZnSO_4$ (sulphate of zinc); the hydrogen displaced now unites with the SO_4 of the contiguous particle of HSO_4, displacing its hydrogen, which seizes SO_4 of the third particle of HSO_4, and so on till the platinum plate is reached, against which the hydrogen of the last particle of decomposed HSO_4 is evolved, because it can find no particle of SO_4 to combine with, and because it cannot enter into chemical union with the platinum, thus—

Before the plates are connected.	*After the plates are connected.*
Zn SO_4H SO_4H SO_4H P	$ZnSO_4$ HSO_4 HSO_4 H $\rightarrow$ P

Now there is nothing in the appearance of the liquid between the plates which indicates the transfer of the disunited elements above alluded to ; and the vessel which contains the acid may be divided by a diaphragm of bladder or of porous earthenware without interfering with the general result. The force must be conceived to travel by a species of *connection*, and the following illustration, to assist us in forming a first notion, was offered by the late Professor Daniell (*Introduction to Chemical Philosophy*) :—

'When a number of ivory balls are freely suspended in a row so as just to touch one another, if an impulse be given to one of the extreme ones, by

striking it with a hard substance, the force will be communicated from ball to ball without disturbing them, till it reaches the more distant, which will fly off under its full influence. Such analogies are remote, and must not be strained too far; but thus we may conceive that the force of affinity receives an impulse in a certain direction, which enables the hydrogen of the first particle of water which undergoes decomposition to combine momentarily with the oxygen of the next particle in succession, the hydrogen of this again with the oxygen of the next, and so on, till the last particle of hydrogen communicates the impulse to the platinum, and escapes in its own elastic form.'

But it is not in the exciting liquid alone that this remarkable transfer of elements takes place; the same power is propagated through the wire which connects the platinum and zinc plates together. To prove this, let the wire be divided in the middle, and having attached to each end a long slip of platinum foil, let each be immersed in a glass jar containing *hydriodic acid*; in a few seconds *iodine* will appear on that slip of foil which is in connection with the platinum plate, and hydrogen gas on the other; so that, supposing a decomposing force to have originated at the zinc plate, and circulated through the exciting acid in the jar to the platinum, and onwards through the wires and through the hydriodic acid back to the zinc, then the hydrogen of the hydriodic acid followed the same course, and discharged itself against the slip of platinum foil in communication with the zinc.

It does not require two metals to form a galvanic circle, or even two different liquids, if other conditions are attended to. A current is established when a zinc plate is cemented into a box, and acted upon on one side by diluted acid, and on the other by solution of salt; or by acting on both sides by the same acid, one surface being rough, and the other smooth, a communication being of course established between the two cells. Common zinc affords a good illustration of a simple galvanic circle: this metal usually contains about one per cent. of iron mechanically diffused through it. On immersion into diluted sulphuric acid, these small particles of zinc and iron form numerous voltaic circles, transmitting the current through the acid that moistens them, and liberating a large quantity of hydrogen gas.

(98) **Sir H. Davy's proposed Copper Protectors.**—In proportion as the contact of two metals in an acid or saline solution increases the affinity of one of them for one element of the solution, it diminishes the liability of the other metal to undergo change. Thus, when zinc and copper are united in diluted acid, the zinc is acted upon *more*, and the copper *less*, than if they were immersed separately. A sheet of copper undergoes rapid corrosion in sea water, the green oxychloride being formed; but if it be associated with another metal more *electro-positive* than itself, such

as zinc, it is preserved, and the zinc undergoes a chemical change. Davy attempted to make an important practical application of this fact. He found that the quantity of zinc requisite to effect a complete preservation of the copper was proportionably very small. A small nail of the former metal will preserve forty or fifty square inches wherever it may be placed; and he found that with several pieces of copper connected by filaments, the fortieth of an inch in diameter, the effect was the same.

Sheets of copper protected by $\frac{1}{40}$ and $\frac{1}{100}$ part of their surface of zinc, and of malleable and cast iron, were exposed during many weeks to the flow of the tide in Portsmouth harbour, their weight before and after the experiment being carefully noted. When the metallic protector was from $\frac{1}{40}$ to $\frac{1}{130}$, there was no corrosion or decay of the copper; with $\frac{1}{200}$ to $\frac{1}{400}$, there was a loss of weight; but even $\frac{1}{1000}$ part of cast iron saved a portion of the copper. It occurred to Davy that this principle might be applied to the preservation of the copper sheathing of ships; but unluckily it was found that, unless a certain degree of corrosion takes place in the copper, its surface becomes foul from the adhesion of sea-weeds and shell-fish. The oxychloride formed when the sheathing is unprotected, acts probably as a poison to these plants and animals, and thus preserves the copper free from foreign bodies, by which the sailing of the vessel is materially retarded. It was proposed by Reinsch (*Jahrb. für Prakt. Pharm.*, vii. p. 94) to cover the copper sheathing of vessels with a thin layer of *arsenic* in the moist way. This coating would cost very little, would not be acted upon by the salt water, and would prevent *molluscæ* from adhering to the bottom of the vessel.

(99) **Modifications of the Simple Galvanic Circle.**

1. *The Original Cylindrical Battery.*—This is shown in Fig. 125. It consists of a double cylinder of copper closed at the bottom, to contain the acid, and a similar but smaller cylinder of zinc, which is kept from touching the sides of the copper by pieces of cork; both are furnished with wires terminated by cups to contain mercury for the convenience of making and breaking the circuit. The *quantity* of electricity set in motion by these simple circles, when on a large scale, is very great, but the *intensity* is very low. No physiological effects are experienced when the body is included in the circuit, nor is water decomposed; their *calorific* powers are, however, so great that they were called by Dr. Hare *calorimotors*.

Fig. 125.

2. *Pepys's Battery, as arranged by him for the use of the Royal Institution.*—This is shown in Fig. 126. It consisted of a

sheet of zinc, and one of copper, coiled round each other, each being sixty feet long and two feet wide; they were kept asunder by the intervention of hair ropes, and suspended over a tub of acid, so that by a pulley or some other simple contrivance they could be immersed and removed. About fifty gallons of dilute acid were required to charge this battery, and its power was of course very great.

3. *Smee's Platinised Silver Battery.*—A cell of this battery is shown in Fig. 127. Its advantages consist in the mechanical help which the finely divided platinum on the surface of the silver affords to the evolution of hydrogen gas. In the ordinary arrangement of copper and zinc, or silver and zinc, the hydrogen gas has a tendency to adhere to the smooth surface of the copper or silver (the negative metals), and its presence in the decomposing liquid has the effect of reducing the sulphate of zinc, and causing a deposition of metallic zinc on the negative metal; thus impairing, and in

Fig. 126.

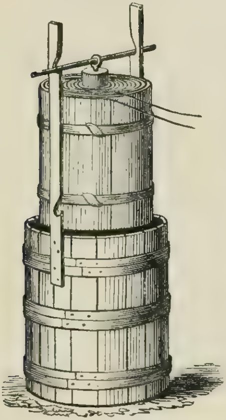
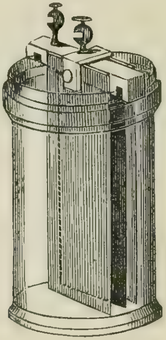


Fig. 127.



the course of time stopping, the action of the battery. In the platinised silver battery a fine powder of metallic platinum is deposited on the silver plate. This is done by immersing the plate in water to which a little dilute sulphuric acid and solution of chloride of platinum have been added. A simple circuit is then formed by connecting the plate metallically with a zinc plate placed in a porous tube containing dilute sulphuric acid. After a short time the silver becomes coated with reduced platinum in the form of a fine black powder. The surface of the silver plate should be roughened by brushing it over with a little strong nitric acid previous to immersing it in the platinum solution.

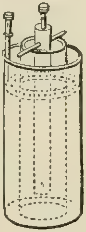
A sheet of platinised silver thus prepared is attached to a beam of wood and is furnished with a binding screw; on either side of it is fixed a plate of amalgamated zinc varying from one-half to the entire width of the silver; these plates are held in their places by a binding screw sufficiently wide to embrace both the zincs and the wood. The arrangement is immersed in a

jar containing a mixture of one part of oil of vitriol and seven parts of water; not the slightest effect is produced till a communication is made by a conductor between the two metals, when torrents of hydrogen gas escape from the negative plate, and an active voltaic current is set in motion.

4. *Daniell's Sulphate of Copper or Constant Battery.*—The hydrogen evolved from the negative plate of a common galvanic battery has a two-fold injurious tendency. In the first place, it reduces the oxide of zinc, and deposits metallic zinc on the negative metal, thereby greatly reducing the circulating force; and secondly, during the assumption of a gaseous form, it interferes with the development of *available* electricity by annulling a considerable portion of that actually generated. It was a desirable object, therefore, to get rid of it altogether, and this Mr. Daniell was the first to effect. He caused the hydrogen liberated by the decomposition of water in the battery to perform chemical work, instead of allowing it to escape as gas.

Fig. 128 represents a single cell of the constant battery; it is a cylinder of copper, in which is placed a cylindrical vessel made of unglazed biscuit ware; in this porous tube a solid rod of amalgamated zinc is introduced, care being taken that it does not touch the porous tube; the copper vessel is filled with a saturated solution of sulphate of copper, with a little sulphuric acid; the porous cell is filled with dilute sulphuric acid, and on a perforated shelf fixed to the upper part of the copper cylinder crystals of sulphate of copper are placed in order to keep the liquid saturated with the saline copper solution. On making a conducting communication between the two metals, water is as usual decomposed, but the hydrogen, instead of being given off in the form of gas, passes through the porous cell, and, entering the copper solution, reduces the oxide of copper, while the sulphate of zinc is retained in the porous cell. If the shelf be kept well supplied with crystals of sulphate of copper, the battery will maintain an equal action for many hours.

Fig. 128.



The manner in which the force is transmitted through the cells may be illustrated by the subjoined diagram, where sulphate of copper is regarded as a compound of copper with the compound radical oxysulphion (SO_4), and dilute sulphuric acid as a compound of hydrogen, with the same radical; the brackets above the symbols indicate the connection of the particles before the plates are brought into contact, and those below, the arrangement of the molecules after the connection has been made, A A representing the porous diaphragm:—

A

$$\mathrm{Cu}\ \overbrace{\mathrm{Cu\ SO_4}}\ \overbrace{\mathrm{Cu\ SO_4}} \leftarrow \overbrace{\mathrm{H\ SO_4}}\ \overbrace{\mathrm{H\ SO_4}}\ \mathrm{Zn}$$

A

When the Daniell battery is required for continued action, it

is better not to amalgamate the zinc plate, and the battery is more constant, though not so powerful, when the zinc cell becomes saturated with sulphate of zinc, provided the salt does not crystallise. Although the porous cell retards, it does not entirely prevent the mixing of the solutions, and after a time much of the copper solution escapes into the zinc cell; the latter should, therefore, be larger than the cell containing the copper solution when continued action is required.[1]

5. *Grove's Nitric Acid Battery.*—In this arrangement the hydrogen is also made to do chemical work. The elements of the battery are platinum, zinc, dilute sulphuric acid, and nitric acid of common strength. The zinc element is a cylinder Z (Fig. 129), open at both ends, and divided longitudinally; this is plunged into a glass or stoneware vessel containing dilute

Fig. 129.

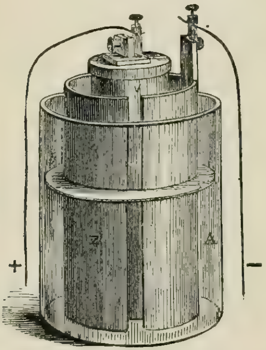
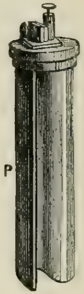


Fig. 130.



sulphuric acid; the platinum plate P (Fig. 130), which may be corrugated to give it greater surface, is immersed in a porous cell containing nitric acid. The energy of this combination is very great; the hydrogen, on emerging from the porous cell, encounters nitric acid, which it decomposes, seizing oxygen, with which it re-forms water, a lower oxide of nitrogen being at the same time produced and dissolved in the nitric acid, which accordingly changes colour, becoming first yellow, then green, and then blue.

The manner in which the force is transmitted is exhibited in the following diagram, where nitric acid is represented by the symbol $(HNO_5O) = (HNO_6)$, and dilute sulphuric acid, as before, by (HSO_4), the brackets above

[1] A battery known as the '*Pile Marie Davy*,' in which sulphate of mercury and carbon electrodes are substituted for the sulphate of copper and copper electrodes of the Daniell battery, was exhibited at the International Exhibition of 1862 by J. A. Deleuil, of Paris. This new form is clean and constant, but it is weaker than Daniell's cell; it has considerable inherent resistance, and is expensive in the first instance, but it has been used to some extent in France for telegraphic purposes.

the symbols indicating the state of union of the particles *before*, and those below the symbols the state of union *after*, the connection between the zinc and platinum has been made :—

$$\begin{array}{c} \text{D} \\ \vdots \\ \text{Pt}\quad \overbrace{\text{HNO}_5\text{O}} \;\vdots\; \overbrace{\text{HSO}_4}\quad \overbrace{\text{HSO}_4}\quad \text{Zn} \\ \vdots \\ \text{D} \end{array}$$

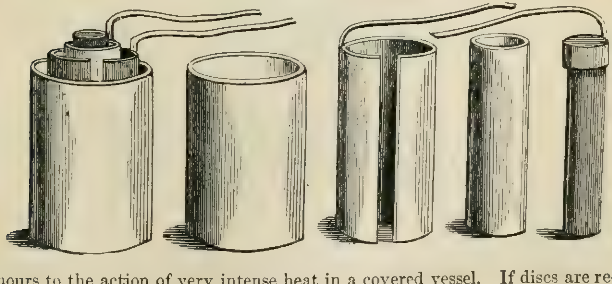
Part of the nitric acid is resolved into water and nitrous acid, which, being dissolved in the undecomposed nitric acid, renders it an excellent liquid conductor.

The superior power of this battery is thus explained by its author (*L. and E. Phil. Mag.*, vol. xv. p. 289):—'In the common zinc and copper battery, the resulting power is the affinity of oxygen for zinc, minus its affinity for copper. In the common constant battery (Daniell's) it is as the same affinity, plus that of oxygen for nitrogen, minus that of oxygen for copper. In the nitric acid battery, the same order of positive affinities, minus that of oxygen for nitrogen. As nitric acid parts with its oxygen more readily than oxide of copper, resistance is lessened, and the power correlatively increased.

'In the common combination, zinc is precipitated on the negative metal, and a powerful opposed force is created; in the sulphate of copper battery, copper is precipitated, and the opposition is lessened; in the nitric acid battery, there is no precipitation, and consequently no counteraction.'

6. *Bunsen's Carbon Battery.*—The substitution of carbon for platinum in the nitric acid battery was the suggestion of Bunsen (*Archives de l'Electricité*, No. vii. p. 103: *Pogg. Ann.*, vol. iv. p. 265). The carbon is prepared by heating together in proper proportions a mixture of well-burnt coke and pit-coal, both in fine powder. The mixture is heated over a moderate charcoal fire in sheet-iron moulds, or in the form of hollow cylinders, by introducing within the iron mould a cylindrical wooden box, and filling with the mixture the interval between the two walls. To render the porous mass compact, it is plunged into a concentrated solution of sugar, and dried until the sugar has acquired a solid consistence. It is afterwards exposed for several

Fig. 131.



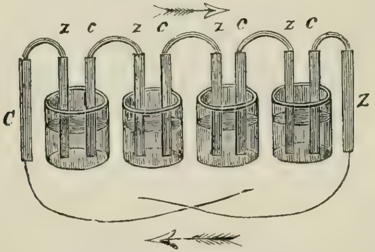
hours to the action of very intense heat in a covered vessel. If discs are required, they are cut out of a cubical block of the prepared carbon, and polished on a plate of greystone. Bunsen's battery has the cylindrical form of Daniell's

(Fig. 131). Each carbon cylinder carries at its upper part a collar of copper, carrying a strip of the same metal, by which it can be metallically connected by means of pinchers with another metal strap soldered to the zinc cylinder in the adjoining cell; care must, however, be taken that the carbon cylinder is sufficiently high, that the part which carries the copper ring shall rise above the glass vessel, and consequently shall in no way come into contact with the nitric acid. It is difficult, however, to prevent this in consequence of the porosity of the carbon, and the ring must therefore be removed and washed every time the battery is used. The porous earthen cell is placed with the carbon cylinder in which is contained the zinc element.

According to Bunsen, with equal surfaces, the powers of a platinum and carbon battery are nearly equal; and according to De la Rive the carbon arrangement is constant for a longer time. It is stated by M. Duchemin that in a Bunsen's battery the nitric acid may be replaced by perchloride of iron, and the sulphuric acid by a solution of chloride of sodium, or, still better, by chloride of potassium.

(100) **Compound Voltaic Circles or Batteries.**—Volta's 'pile' (Fig. 120, p. 167) was the first compound battery that was constructed; it is easy, however, to see that many inconveniences must attach to it when the plates are numerous; in addition to the trouble of building it up, it is frequently rendered comparatively inactive by the moisture pressed out of the lower part by the weight of the upper; hence the substitution of troughs and other arrangements. Volta's '*couronnes des tasses*' (Fig. 132) is

Fig. 132.

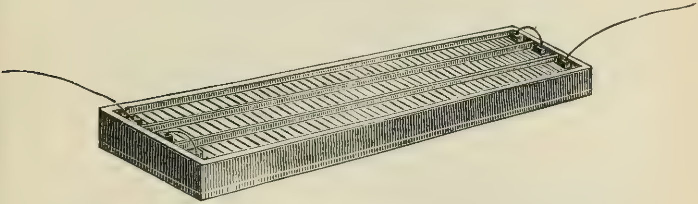


the most simple of these arrangements. This consists of a row of small glasses or cups containing dilute sulphuric acid, in each of which is placed a small plate of copper, about two inches square, and another similar-sized plate of zinc, not touching each other, but so constructed that the zinc plate of the first glass may be in metallic communication with the copper of the second, the zinc of the second with the copper of the third, and so on, throughout the series. By this arrangement, when glasses are employed, we can see what is going on in each cell; and if the zinc plates be

amalgamated, it will be observed that, when the wires are connected, and consequently when a current is passing, all the copper surfaces are rapidly evolving hydrogen gas, while the solution of the zinc proceeds quietly; but that, when the connection between the extreme plates is broken, the evolution of gas ceases. Eighteen or twenty pairs of plates will decompose acidulated water rapidly, and thirty will give a distinct shock to the moistened hands.

2. *Cruickshank's Battery.*—In this modification, shown in Fig. 133, the plates are fixed in pairs in a trough of wood, so that the

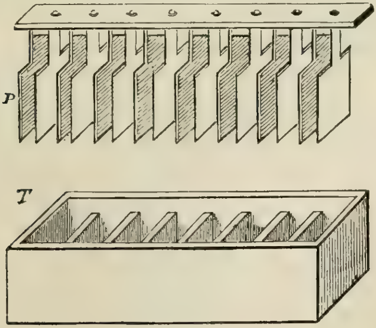
Fig. 133.



exciting liquid, which may be either dilute sulphuric acid or solution of sulphate of copper, may be easily removed and renewed.

3. *Babington's Battery* (Fig. 134).—The plates of copper and

Fig. 134.



zinc, usually about four inches square, are united in pairs by soldering at one point only; the trough in which they are im-

mersed is made of earthenware, and divided into ten or twelve equal compartments. The plates are attached to a strip of wood, and so arranged that each pair shall enclose a partition between them; by this arrangement the whole set may be lifted at once into or out of the cells; and thus, while the fluid remains in the trough, the action of the plates may be suspended at pleasure, and, when corroded, easily replaced. The piece of wood to which the plates are attached should be well dried, and then varnished in order to render it a non-conductor of electricity. When several of these troughs are to be united together, it is necessary to be careful in their arrangement, as a single trough *reversed* will very materially diminish the general effect. Care must also be taken to insure perfect communication between the several plates.

4. *Wollaston's Battery.*—The copper plate is here doubled, so as to oppose it to both surfaces of the zinc, as shown in Fig. 135.

Fig. 135.

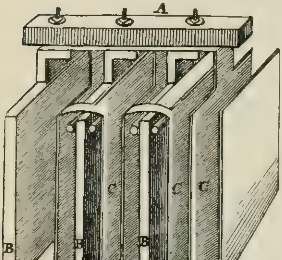
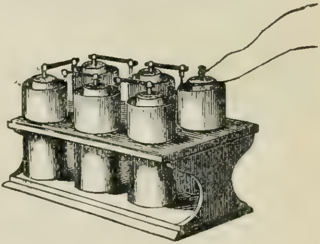


Fig. 136.



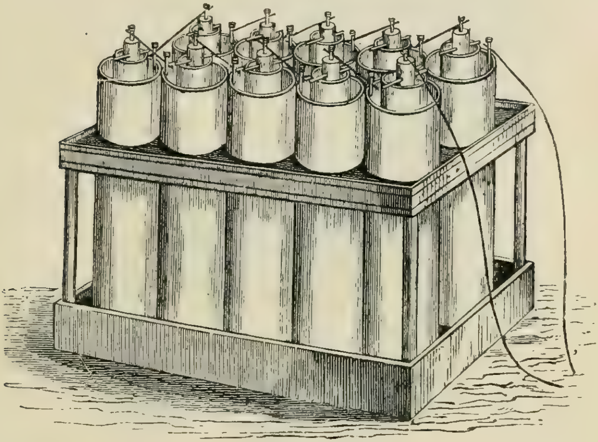
A represents the bar of wood to which the plates are screwed; B B B the zinc plates connected with the copper plates C C C, which are doubled over the zinc plates. Contact of the surfaces is prevented by pieces of wood or cork placed between them. Ten or twelve troughs on this construction form an efficient voltaic battery.

5. *Daniell's Compound Battery.*—A set of six is shown in Fig. 136, and a large set of ten in Fig. 137. A series of thirty cells of the smaller size, six inches high and three and a half inches in diameter, forms a powerful battery; and a series of seventy cells of the larger size, when arranged in a single series, between charcoal terminals, produces a voltaic arc the heat of which is sufficiently intense to fuse bars of platinum one-eighth of an inch square, and

to melt in considerable quantities the most infusible metals, such as rhodium, iridium, and titanium.

In one form or another, Daniell's battery is now chiefly used by the large telegraph companies. A very compact arrangement was exhibited at the International Exhibition of 1862 by Messrs. Reid Brothers (*Jurors' Report*). A glass trough is subdivided into cells by five partitions; this cellular trough is formed of one

Fig. 137.

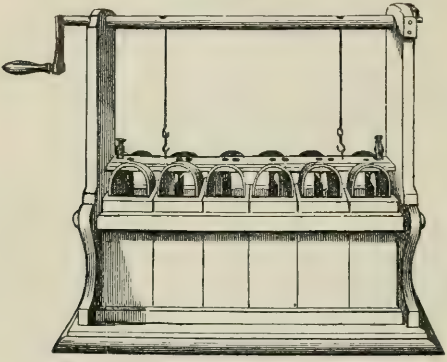


solid piece of glass. Each cell is again subdivided by a porous plate, cemented at each side and at the bottom between two cheeks. The zinc and copper plates connected in pairs stand astride the glass partitions, and the subdivisions are alternately filled with sulphate of copper and acidulated water. This battery is strong and portable, but the porous plates, when worn out, can only be removed and replaced with difficulty.

6. *Smee's Compound Battery.*—A set of six cells, arranged for intensity effects, is shown in Fig. 138; the plates are raised from, and immersed into, the cells by means of a winding apparatus. A series of ten or twelve forms an efficient battery. It is important in using this arrangement to take care that no salt of copper, lead, or other base metal be dropped into the exciting liquid, as in that case there is a chance of getting a deposit on the negative metal. A useful form of Smee's battery for telegraphic purposes was exhibited at the International Exhibition of 1862 by E. Tyer

(*Jurors' Report*). The zinc plates can be readily removed, cleaned, and replaced; they lie in a saucer of mercury, which fulfils the double purpose of maintaining the zinc constantly amalgamated, and of making contact between the copper and zinc strip which connects the zinc with a platinised silver plate in the next cell. This copper strip is insulated by gutta-percha, except where covered by the mercury. Very little local action can take place, owing to the thorough and constant amalgamation of the zinc; and, therefore, if the circuit be only occasionally closed for short periods, it will remain very constant. Mr. Walker substitutes *graphite* for

Fig. 138.



platinised silver in his modification of Smee's battery, and he has more recently platinised the graphite, by which, he states, the liberation of hydrogen is much facilitated, and polarisation, one great defect of single-fluid batteries, much diminished. The cost of the platinising process is about one halfpenny per plate of 7 inches by 3 inches. The platinised plates are said also to keep much cleaner than the simple graphite plates.

7. *Grove's Compound Battery.*—A set of four cells arranged in series is represented in Fig. 139, and in section, Fig. 140, and the first set of plates removed from the porcelain through D shews clearly the arrangement. *A a* is the bent zinc plate, B the platinum plate in its porous cell, C the next platinum plate, connected by means of a binding screw with the zinc at *a*.

A series of five cells of this battery, containing altogether about four square feet of platinum, liberated from acidulated water 110 cubic inches of oxygen and hydrogen gases per minute. A series of fifty cells, the platinum plates being two inches by four, produced between charcoal points a volumi-

nous flame one inch and a quarter long, and dissipated, in the form of oxide, bars of various metals. With an arrangement of one hundred cells, the

Fig. 139.

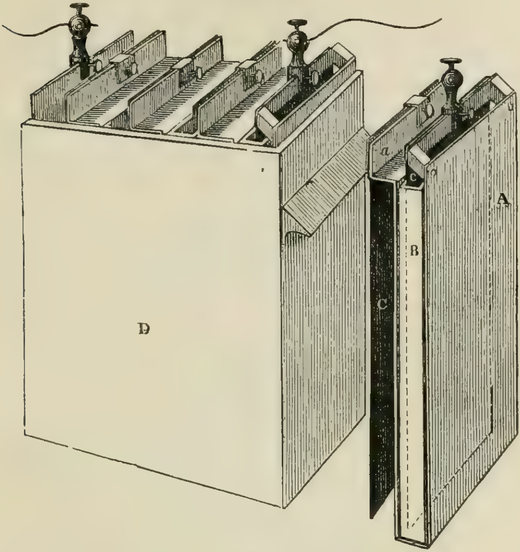
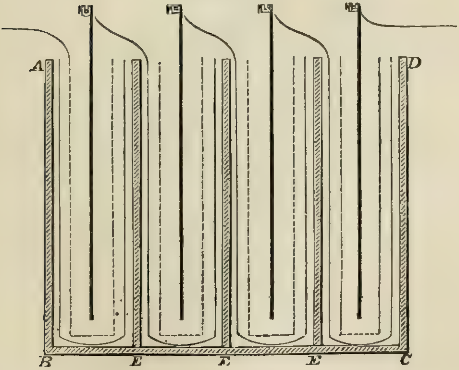


Fig. 140.



flame between charcoal terminals is exceedingly voluminous, and so brilliant as to be almost insupportable to the naked eye; upwards of two feet of

stout iron wire are heated to whiteness, and ultimately fused; sulphuret of antimony is decomposed, and the metal brilliantly deflagrated.

(101) **Passive State of Iron.**—When iron wire is immersed in nitric acid (sp. gr. 1·35), it is attacked with violence; but it was first noticed by Sir John Herschell that, if the wire be associated with a piece of gold or of platinum, it is quite inactive in acid of that strength. Once touching the wire while in the acid with platinum or gold is sufficient to render it inactive, and to cause it to continue so, even after the removal of the platinum or gold, but on touching it with another piece of iron or zinc wire, it is immediately powerfully acted upon. Heat has a similar effect in causing iron wire to assume an inactive state: if one-half of a piece of wire be heated in a spirit-lamp until a blue tinge is visible, and then allowed to cool, the end that has been heated is quite passive in nitric acid, the unheated end being powerfully acted upon; if now the heated end be rubbed bright with sand-paper, its active condition is restored.

When an inactive wire and one that is active are dipped into a glass containing nitric acid, and made to touch *above* the liquid, action is excited in the indifferent wire.

When an active wire is associated with a passive wire, and both plunged into the acid, the *passive* wire entering the liquid *first*, the active wire is rendered passive; this wire will now render another common iron wire passive, the second wire will destroy the activity of a third wire, and so on; if the wires be removed from the acid, wiped, and then reintroduced, their active condition is found to be restored; but they are again rendered passive by repeating the process above described.

When an iron wire protected by platinum is immersed in a solution of nitrate of copper in nitric acid, it remains bright; if the protecting platinum be removed immediately after the immersion of the associated metals in the saline solution, metallic copper is generally immediately precipitated upon the iron wire, but if the two metals be allowed to remain in contact for an hour or so, the iron wire will retain its brightness in the solution for any length of time, if undisturbed.

If a long passive wire be placed in a vessel containing nitric acid, and a piece of ordinary iron wire bent into the form of a fork be slid down it into the acid, it assumes the passive condition; if the long wire be removed, the fork continues inactive, but is instantly thrown into action by touching it with another piece of ordinary wire.

Let one end of a platinum wire be connected with one extremity of a galvanometer, and let the other dip into a glass containing

nitric acid; if now one end of a piece of ordinary iron wire be connected with the other extremity of the galvanometer, and the opposite end of the wire dipped into the acid, the latter will be found to have no action upon it, and the needle of the galvanometer will remain stationary; let it now be touched with an ordinary iron or zinc wire, it will immediately start into activity, and the needle of the galvanometer will be violently deflected. In this experiment a piece of iron wire that has been rendered inactive may be substituted for the platinum wire.

If several glasses be filled with nitric acid, and connected together by arcs of associated platinum and iron wires, the circuit being established, as in the above experiment, through the galvanometer, the wires in all the glasses will remain passive until the iron in *one* is touched in the acid by an ordinary wire; the wires in *all* the glasses are then thrown into activity, the galvanometer being powerfully deflected.

A voltaic battery consisting of zinc and passive wire, or of passive and active iron, in either case excited after the manner of a Grove's battery, was described by Professor Schönbein; its power was stated to be very great; it is not, however, an arrangement to be recommended.

8. *Callan's Compound Cast-Iron Battery.*—Cast iron and zinc form an effective voltaic circle. Mr. Sturgeon first suggested the use of these metals (*Annals of Electricity*, vol. v.) A prodigious battery, the largest probably that was ever made, was constructed by Professor Callan, of Maynooth, cast iron being the negative element (*Phil. Mag.*, vol. xxviii. p. 49). It consisted of 300 cast-iron cells, each containing a porous cylinder holding a zinc plate four inches square; 110 cast-iron cells, each holding a porous cylinder and zinc plate six inches by four; and 177 cast-iron cells, each containing a porous cell and a zinc plate six inches square. The entire battery consisted, therefore, of 577 voltaic circles, containing *ninety-six* square feet of zinc, and about *two hundred* square feet of cast iron. It was charged by pouring into each cast-iron cell a mixture of twelve parts of concentrated nitric acid and eleven and a half of strong oil of vitriol, and by filling to a proper height each porous cell with dilute nitro-sulphuric acid, consisting of about five parts of sulphuric acid, two of nitric, and forty-five of water. In charging the entire battery, there were used about fourteen gallons of nitric and sixteen gallons of sulphuric acid.

The discharge of this battery through a very large turkey instantly killed it. In order to give the shock, a piece of tin foil about four inches square was placed under each wing, along the sides of the bird, which were previously stripped of their feathers and moistened with dilute acid. The foil was kept

in close contact with the skin by pressing the wings against the sides. The person who held the bird had a very thick cloth between each hand and the wing in order to save him from the shock. When the discharge took place, the craw of the turkey was burst.

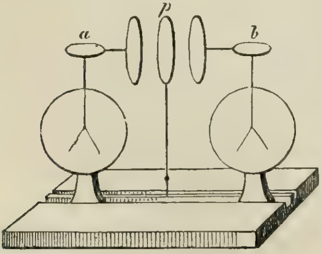
When a copper wire in connection with the negative end of the battery was put in contact with a brass ring connected with the positive end, a brilliant light was instantly produced. The copper wire was gradually separated from the brass ring until the arc of light was broken. The greatest length of the arc was about *five inches.*

(102) **The Water Battery.**—When a series of some hundred couples of zinc and copper are arranged voltaically, and charged with common water, a battery is obtained, the electricity of which is of a high degree of intensity, resembling that of the common electrical machine; indeed, by connecting the extremities of such an arrangement with the inner and outer coatings of a Leyden battery, it becomes charged so instantly that almost continuous discharges may be produced.

Mr. Crosse arranged 2,400 pairs of copper and zinc plates, paying great attention to insulation. When the opposite poles of the series were connected with the inner and outer coatings of a Leyden battery containing 73 feet of surface, a continued charge was maintained, each discharge being accompanied by a loud report, piercing letter-paper, and fusing silver leaf and platinum wire.

Mr. Gassiot subsequently constructed a water battery of 3,520 pairs of copper and zinc cylinders, each pair being placed in a separate glass vessel, well covered with a coating of lac varnish. Notwithstanding all the precautions taken, the insulation was still imperfect, nor does perfect insulation seem attainable for any lengthened period with such an extended series. The following experiments with this battery are described by Mr. Gassiot (*Phil. Trans.* 1844):—

Fig. 141.



'On connecting the copper wire from the extreme cells with the plates *a b* of the double electroscope (Fig. 141), the condensing plate *p* being removed, this instantly produced a considerable and steady divergence of the leaves; and on applying the usual tests, the plate *b*, connected with the copper extremity, gave signs of *positive*, and *a*, connected with the zinc, signs of *negative* electricity. If *a* was connected with one extremity of the battery, the other extremity being connected or not with the ground, the same general effects occurred; the divergence of the leaves corresponded with the

connection, and the leaves of *b* diverged by induction ; if in this state *b* was touched, and then removed from the influence of *a*, it was found to be charged with the opposite electricity.

'The assumption of *polar tension* by the elements constituting the battery, *before the circuit was completed*, was shown, not only by the effect on the leaves of the electroscope when placed within two or three inches of either end of the battery, or over either of the terminal cells, but by the production of a *spark* between the terminal wires through a space of one-fiftieth of an inch. When the double electroscope (Fig. 141) was included in the circuit, and the discs *a* and *b* closely approximated, the sparks became a *stream of fire*, which on one occasion were continued uninterruptedly for upwards of five weeks. An experimenter standing on the ground could draw sparks from either terminal.

'For testing the presence of what is usually called the *current*, two trays containing 160 cells of the battery were removed and most carefully insulated. A very delicate galvanometer was interposed between the zinc terminal of one tray and the copper terminal of the other, but not the slightest deflection of the needle took place, neither was there the slightest indication of the liberation of iodine when a piece of bibulous paper saturated with iodide of potassium was substituted for the galvanometer; the inference from which is, that there was no definite chemical action taking place in any cell of the battery, and that the *electric* or *static* effects take place *before* or *independently of the actual development of the chemical effects.*

'A copper wire attached to the negative end of the battery was connected with the galvanometer, and this with the plate *a* of the double electroscope (Fig. 141) ; a platinum wire attached to the positive end rested on a piece of bibulous paper moistened with iodide of potassium ; another wire also resting on the paper was connected with the plate *b* of the electroscope. By a mechanical arrangement the plates could be approximated or separated as required. On approximating the plates so as to permit sparks to pass at intervals of about a second, a tremulous motion was imparted to the needle of the galvanometer, but when they were brought so nearly in contact as to permit the discharges to take place in quick succession, the needle was steadily deflected, and iodine was freely evolved, proving that chemical action was taking place in each cell, and that the current is a collection or accumulation of discharges of electricity of tension. When 320 cells were employed, the greatest care being taken to insure perfect insulation, not the slightest evidence of any chemical action taking place in the cells could be obtained previous to completing the circuit, although there was sufficient intensity to elicit sparks through $\frac{1}{100}$ of an inch.'

The following conclusions were deduced by Mr. Gassiot from his experiments with this extraordinary battery :—

1. That the elements constituting the voltaic battery assume *polar tension* before the circuit is complete.

2. That this tension, when exalted by a series of pairs, is such that sparks will pass between the terminals of the battery *before* their actual contact.

3. That these static effects precede and are independent of the completion of the voltaic circuit, as well as of any *perceptible* development of chemical or dynamic action.

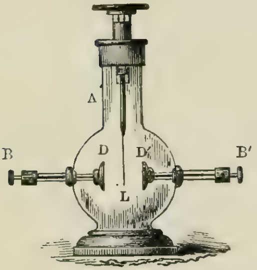
4. That the current may be regarded as a series of discharges of electricity of tension succeeding each other with infinite rapidity.

5. That the rise of tension in a battery occupies a measurable portion of time.

6. That the *static* effects elicited from a voltaic series are a direct evidence of the first step towards chemical combination or dynamic action.

(103) **Polar Tension before Contact in a Single Cell.**—With the aid of the electroscope shown in Fig. 142, the Rev. Charles Pritchard (*Phil. Trans.* 1844) succeeded in obtaining signs of tension before contact in a single cell of a voltaic battery. A is a glass vessel, the stem of which is well coated with lac; B B′ two copper wires passing through glass tubes and corks; D D gilt discs, each about two inches in diameter, attached to the wires; P a copper plate with a wire passing through a glass tube; to the end of this wire is attached a narrow lip of gold leaf, L. The discs must be adjusted with care, so as to allow the leaf to be equidistant from each. If B be connected by a wire attached to the platinum, and B′ to another wire attached to the zinc of a single cell of the nitric acid battery insulated on a plate of lac, and if an excited glass rod be approximated very gradually towards the plate P, the gold leaf will be attracted to B′, or the disc attached to the zinc; and if a stick of excited resin be approximated in a similar manner, the gold leaf will be attracted to B, or the metallic disc attached to the platinum.

Fig. 142.



(104) **Polarisation: Secondary Batteries.**—If a piece of moistened paper be placed on a slip of glass, and made to complete the circuit of a voltaic battery, it is found to become *electro-polar*—that is, that half which was in contact with the positive extremity of the battery becomes positive, and that portion next the negative end becomes negative—and this electrical condition of the paper remains for some time after its removal from between the poles of the battery, provided its insulation be maintained. This fact was first observed by Volta, and it occurred to Ritter that a pile might be constructed of alternations of moistened cloth and a single metal, which should theoretically receive a charge similar to that of the moistened paper, by being placed in conducting communication with the opposite extremities of a voltaic pile. On trying the experiment, he found such to be the case;

the pile which he termed the 'secondary' pile retaining its electrical state, and exhibiting electrical phenomena similar to that of the 'primary' pile for some time after its connection with the latter is broken. In like manner, a number of plates of the same metal, platinum, or lead may be polarised by passing a current from a voltaic battery through them ; on breaking contact the effects of a voltaic pile are for a short period obtained from the secondary battery. The same sort of polarisation is produced in a single pair of platinum plates by connecting them with the poles of a battery while immersed in common or acidulated water, the effect being due to the films of hydrogen and oxygen which collect on the negative and positive plates respectively, as may be proved by plunging the plate which had been connected with the positive pole of the battery into a graduated tube filled with hydrogen, and the other into a tube filled with oxygen ; both gases are gradually absorbed, the hydrogen disappearing twice as fast as the oxygen. Indeed, a pair of platinum plates may be polarised without the aid of a voltaic battery, namely, by simply plunging one plate into a jar of hydrogen, and the other in a jar of oxygen gas. If the two plates be now connected with a galvanometer, and quickly plunged into water, a current is obtained, passing from the plate which had been immersed in the hydrogen through the liquid to that which had been immersed in the oxygen.

A secondary battery of great power is described by Planté (*Comptes Rendus*, March 26, 1860). He states that a battery with electrodes of lead has $2\frac{1}{2}$ times the electromotive force of one with electrodes of platinised platinum, and 6 times as great as that of one with ordinary platinum. This great power arises from the powerful affinity existing between *peroxide of lead* and *hydrogen*, a fact first noticed by De la Rive.

The secondary battery recommended by Planté has the following construction:—

It consists of nine elements, presenting a total surface of 10 square metres. Each element is formed of two large lead plates rolled into a spiral, and separated by coarse cloth, and immersed in water acidulated with $\frac{1}{10}$ of sulphuric acid. The kind of current used to excite this battery depends on the manner in which the secondary couples are arranged. If they are arranged so as to give three elements of triple surface, five small Bunsen's cells, the zincs of which are immersed to a depth of 7 centimetres, are sufficient to give, after a few minutes' action, a spark of extraordinary intensity when the current is closed. The apparatus plays, in fact, just the part of a condenser, for by its means the work performed by the battery after the lapse of a certain time may be collected in an instant.

An idea of the intensity of the charge will be obtained by remembering that, to produce a similar effect, it would be necessary to arrange 300 Bunsen's elements of the ordinary size (13 centimetres in height), so as to form four or

five elements of $3\frac{1}{2}$ square metres of surface, or three elements of still greater surface.

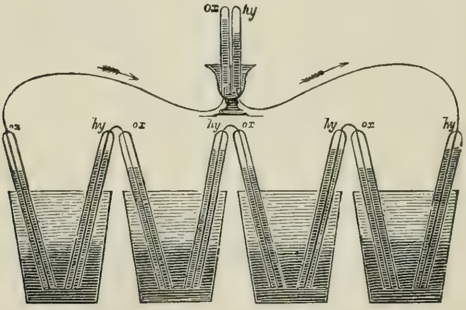
If the secondary battery be arranged for intensity, the principal battery should be formed of a number of elements sufficient to overcome the inverse electromotive force developed. For *nine* secondary elements, about 15 Bunsen's cells should be taken, which might, however, be very small.

From the malleability of the metal employed, this battery is readily constructed. By making the plates of lead sufficiently thin, a large surface may be placed in a small space.

The nine elements used by Planté are placed in a box 36 centimetres square, filled with liquid once for all, and placed in closed jars, so as to be ready for immediate use whenever it is desired to procure by means of a weak battery powerful discharges of dynamic electricity. The use of secondary electric currents for telegraphic purposes had been previously proposed by Jacobi.

(105) **The Gas Battery.**—Mr. Grove succeeded in obtaining a continuous current from the secondary currents produced by polarised plates, and in constructing a perfectly novel battery, in which the active elements are gases (*Phil. Mag.*, Dec. 1842; *Phil Trans.*, part ii. 1843, and part ii. 1845). It consisted originally of a series of 50 pairs of platinised platinum plates, each about a quarter of an inch wide, enclosed in tubes partially filled alternately with oxygen and hydrogen gases, as shown in Fig. 143. The liquid in

Fig. 143.



the tubes was dilute sulphuric acid (sp. gr. 1·2), and the following effects were produced:—

1. A shock was given which could be felt by five persons joining hands, and which, when taken by a single person, was painful.

2. The needle of a galvanometer was whirled round, and stood at about 60°; with one person interposed in the circuit, it stood at 40°, and was slightly deflected when two were interposed.

3. A brilliant spark, visible in broad daylight, was obtained between charcoal terminals.

4. Iodine of potassium, hydriodic acid, and water acidulated with sulphuric acid were severally decomposed; the gas from the decomposed water was eliminated in sufficient quantity to be collected and detonated. The gases were evolved in the direction denoted in the figure, i.e. as the chemical theory and as experience would indicate, the hydrogen travelling in one direction throughout the circuit, and the oxygen in the reverse. It was found that twenty-six pairs were the smallest number that would decompose water, but that four pairs would decompose iodide of potassium.

5. A gold-leaf electroscope was notably affected.

When the tubes were filled with atmospheric air, no effect was produced, nor was any current determined when the gases employed were carbonic acid and nitrogen, or oxygen and nitrogen.

In order conveniently to examine the gases either after or during an experiment, without changing the liquid in which the tubes were immersed, Mr. Grove adopted the form of cells shown in Figs. 144 and 145.

b c d e is a parallelopiped glass or stoneware vessel. The tubes are cemented with pieces of wood, *a b*, *a c*, and can with the wood be separately detached from the trough, as seen in Fig. 145. At the aperture or space *a a* between the tubes there is just sufficient room for a finger to enter; close the orifice of either tube, and thus remove

Fig. 144.

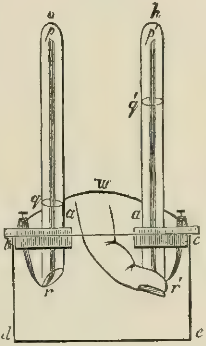
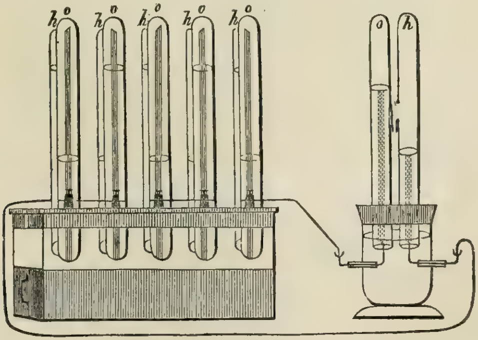


Fig. 145.

Fig. 146.



it from the apparatus. The platinum foil is turned up round the edge of the tube, and brought into communication with a binding screw fixed into the wood. A battery of five cells thus arranged, charged with oxygen and hydrogen gases, and connected with an apparatus for decomposing water, is shown in Fig. 146. With the battery of 50 of these cells there was but a trifling difference in the rise of the liquid in all the cells, and the rise of gas in the decomposing apparatus was exactly in the same proportion. The hydrogen tube is analogous to the zinc plate of an ordinary voltaic battery.

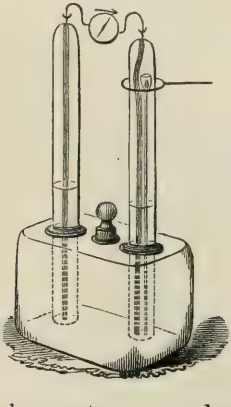
The following results were obtained with other gases, ten cells being employed :—

Oxygen and protoxide of nitrogen .	No effect on iodide of potassium.
Oxygen and deutoxide of ditto .	Very slight, soon ceasing.
Oxygen and olefiant gas . .	Very feeble, but continuous.
Oxygen and carbonic oxide . .	Notable effects. Slight symptoms of decomposing water.
Oxygen and chlorine . . .	Considerable action at first, scarcely perceptible in 24 hours.
Chlorine and dilute sulphuric acid .	About the same.
Chlorine and hydrogen . . .	Powerful effects. Two cells decomposing water.
Chlorine and carbonic oxide . .	Good. Ten cells decomposing water.
Chlorine and olefiant gas . .	Feeble.

With respect to the theory of the gas battery, Mr. Grove remarks :—

'Applying the theory of Grotthus to the gas battery, we may suppose that, when the circuit is completed at each point of contact of oxygen, water, and platinum in the oxygen tube, a molecule of hydrogen leaves its associated molecule of oxygen to unite with one of the free gas ; the oxygen thus thrown off unites with the hydrogen of the adjoining molecule of water, and so on, until the last molecule of oxygen unites with a molecule of the free hydrogen : or the action may conversely be assumed to commence in the tube containing the hydrogen.'

Fig. 147.



The form of gas battery employed by Mr. Grove in his later experiments is shown in Fig. 147. It possesses the advantage of entirely preventing the interfering action of the atmosphere. In this arrangement oxygen and deutoxide of nitrogen gave a continuous current ; and a permanent deflection of the galvanometer was produced when a piece of phosphorus was suspended in one of the tubes filled with nitrogen, the other containing

oxygen, the product being phosphorous acid; and a curious instance was exhibited of the employment of a solid insoluble non-conductor, and the existence of a continuous voltaic current, and of a true combustion, the combustible and the *comburant* being at a distance: phosphorus burned by oxygen, which is separated from it by strata both of water and gas of indefinite length.

A current was likewise produced by *sulphur* in nitrogen, the sulphur being contained in a little capsule of glass that could be heated by a small hoop of iron with a handle, as shown in the figure. The moment the sulphur entered into fusion, the needle of the galvanometer moved, and it continued deflected during the whole time it remained in the fused state. Various other substances, such as *camphor*, *oil of turpentine*, *oil of cassia*, *alcohol*, *ether*, &c., were thus tried, and all produced notable effects.

CHAPTER IX.

VOLTAIC ELECTRICITY (*continued*).

Simple and Compound Circles—Ohm's Law and its Applications—Wheatstone's Bridge, Rheostat, and Resistance Coils—Standards of Electrical Resistance.

(106) **Simple and Compound Voltaic Circles.**—The *quantity* of electricity set in motion by a simple voltaic circle when the plates are large is very great, though its *intensity*, or its power of overcoming resistances, is low. The energy depends on the size of the plates, the intensity of the chemical action on the oxidisable metal, the rapidity of its oxidation, and the speedy removal of the oxide. In the smallest voltaic circle the quantity of electricity thrown into circulation is almost infinitely greater than that from the ordinary electrical machine: indeed, it has been shown by Faraday (*Ex. Resear.*, 371 *et seq.*) that two wires, one of platinum and one of zinc, each *one-eighteenth* of an inch in diameter, placed *five-sixteenths* of an inch apart, and immersed to the depth of *five-eighths* of an inch in acid consisting of one drop of oil of vitriol and four ounces of distilled water, at a temperature of about 60°, and connected at the other extremities by a copper wire eighteen feet long, and one-eighteenth of an inch thick, yield as much electricity in eight beats of a watch, or $\frac{8}{150}$ of a minute, as an electrical battery consisting of fifteen jars, each containing 184 square inches of glass coated on both sides, and charged by thirty turns of a fifty-inch plate electrical machine.

But it is not necessary that the plates composing a simple voltaic circle should consist of *two* opposed surfaces only. The same

electrical effect is obtained if the plates are cut up into a number of pieces and placed in different vessels, each containing the same exciting fluid, provided the same extent of surface be preserved, and the pieces be kept at the same distance apart. Thus let a plate of copper and another of amalgamated zinc, each four inches square, be immersed at a distance of one inch apart in dilute sulphuric acid, and connected by a stout copper wire; after the lapse of a certain time a certain quantity of zinc will be dissolved and a corresponding quantity of hydrogen gas will be evolved on the surface of the platinum; now let each plate be cut into four strips, each one inch broad and four inches long, and let a pair of each metals be immersed, at a distance of one inch apart, in four separate vessels containing dilute sulphuric acid; let all the platinum plates be connected together by a stout copper wire, and all the zinc plates by a similar wire, and let the two wires be united; the same amount of zinc will be dissolved in the same time, the same amount of oxygen liberated, and the same quantity of electricity thrown into circulation, as with a single pair; the four pairs and the single pair are equally *simple* voltaic circles.

But the four pairs may be differently arranged. Instead of connecting all the platinum plates together, and all the zinc plates together, the platinum plate in vessel No. 1 may be connected with the zinc plate in vessel No. 2, the platinum plate in vessel No. 2 with the zinc plate in vessel No. 3, and so on, the platinum plate in the last vessel being united by a stout wire with the zinc plate in the first. Under this arrangement the amount of zinc dissolved and of hydrogen liberated will be precisely the same as before, but the *electromotive force is increased fourfold*; at the same time the resistances are still more increased, for whereas in the first arrangement a stratum of liquid four inches wide and one inch thick had to be traversed, in the second arrangement the current has to pass through four separate inches of liquid, each one inch in width. But, in consequence of the mode of connecting the plates, there is a starting-point of power in each cell, and each contributes its energy in urging forward the current; although, therefore, the quantity of electricity is no greater than when the plates are arranged as a single pair, its intensity or power of overcoming resistance is far greater, and this power is within certain limits increased in proportion as the number of pairs of plates is increased. As thus arranged, the plates constitute a *compound* voltaic circle.

(107) **Meaning of the terms Electromotive Force, Electrical Resistance, Electrical Current, Quantity, and Tension.** —By the term *electromotive force* is to be understood that quality of a battery or source of electricity in virtue of which it tends to

do work by the transfer of electricity from one point to another, and this force is measured by measuring the work done during the transfer of a given quantity of electricity between those points. The work done, whether it be mechanical, or chemical, or thermal, was proved experimentally by Dr. Joule to be proportional to the *square* of the current, to the *time* during which it acts, and to the resistance of the circuit.

By the term *electrical resistance* is to be understood that quality of a conductor in virtue of which it prevents the performance of more than a certain amount of work in a given time by a given electromotive force. The resistance of a conductor is therefore inversely proportional to the work done in it when a given electromotive force is maintained between the two ends.

By the term *electrical current* is meant the cause of the peculiar properties possessed by a conductor used to join the opposite poles of a voltaic battery, those, namely, of exerting a force on a magnet in its neighbourhood; of decomposing certain compound bodies called electrolytes when any part of the conductor is formed of such compound bodies; or of producing currents in neighbouring conductors as they approach or recede from them.

The force with which one electrified body acts upon another at a constant distance varies under different circumstances. When the force between the two bodies at this constant distance, and separated by air, is observed to increase, it is said to be due to an increase in the *quantity* of electricity, and the quantity at any spot is defined as proportional to the force with which it acts through air on some other constant quantity at a distance. If two bodies charged with a given quantity of electricity are incorporated, the single body thus composed will be charged with the sum of the two quantities.

The above definitions of the terms *electromotive force*, *resistance*, *current*, and *quantity*, are those adopted by Professor T. Clerk Maxwell and Mr. Fleeming Jenkin in their report 'On Standard Electrical Resistance,' as members of a committee appointed by the British Association (see *Report*, 1863). Mr. Latimer Clark (*Proceedings of the Royal Institution*, March 15, 1861) points out that the expression *intensity*, as ordinarily used, involves two perfectly distinct qualities, viz. *tension*, or *electromotive force*, or *electric potential*, and *quantity*. All the most striking properties of electricity, such as the decomposition of water and salts, the combustion of metals, the deflection of the galvanometer, the attraction of the electro-magnet, and the physiological effects of the current, are really dependent as regards their magnitude and energy solely on the *quantity* of electricity passing. Their greater energy,

when the tension is increased, is an indirect effect due not to that tension but to the increased quantity which passes in a given time by reason of the increased tension. A galvanometer consisting of a few turns only of thick wire is deflected as powerfully by one cell of a voltaic battery as by 6 or even by 600; provided the cells are all of the same size, because the thick wire is capable of conveying freely the whole quantity of electricity which one cell can produce, and this is the same as that produced by the whole 600; on the other hand, a galvanometer with many thousand turns of fine wire gives the same deflection with a battery formed of a small gun-cap as with one of twenty square feet of surface, because the quantity in this case is regulated and limited not by the size of the plates, but by the power of conduction in the wire, the quantity being therefore the same in both cases. In every case the deflection is dependent solely on the quantity of electricity actually passing through the instrument without reference to its tension.

The ignition of metals is a phenomenon dependent on quantity and not on tension; thus one cell of a battery will ignite a certain length of platinum wire, but by the addition of two or three more cells two or three times the length of wire will be ignited, the quantity passing in the greater length being under the higher tension precisely the same as in the original length. In this sense is to be understood Faraday's remark, 'that the same quantity of electricity which would ignite an inch of wire would ignite a foot or a mile of the same wire.'

A battery of two or three cells which will readily fuse platinum wire, produces no shock, because, although the *quantity* of electricity is abundant, the tension is low; on the other hand, a battery of a great number of pairs of small plates may give an intolerable shock to the system, although from its deficiency in quantity it may have scarcely any power to fuse platinum wire.

The fall of *tension* is always accompanied by its conversion into heat; the ignition of wire by the voltaic current, the intense heat of the voltaic arc, and the heat and light of the electric discharge and of the spark are all cases of the evolution of heat in consequence of a fall of tension, and the quantity of heat evolved is apparently directly proportionate to the fall of tension within a given space, and to the quantity of electricity passing.

(108) **Ohm's Law.**—Under no circumstances do we obtain in the form of a current the whole of the electricity produced by the chemical actions going on in the battery. The amount of electricity realised, or, in other words, the force of the current, is equal to the sum of the electromotive forces divided by the sum of the

resistances in the circuit. Thus let F denote the actual force of the current, that is, its power to produce heat, magnetism, chemical action, or any of its other effects; E the electromotive force, and R the resistance of the wires and liquids, then

$$F = \frac{E}{R}.$$

The different causes which influence the quantity of electricity obtained in a voltaic circuit, were investigated mathematically by Professor Ohm, of Nuremberg, and his formulæ, which have been verified experimentally by Daniell, Wheatstone, and others, may be regarded as the basis on which all the investigations that have since been made relative to the force of the current have been founded.

By increasing the number of elements of a voltaic battery, we increase the tension, urging the electricity forward, as has already been observed, but at the same time we increase the amount of resistance offered by the liquid portion of the circuit; so that, provided in both cases the circuit be completed by a competent conductor, such as a stout copper wire, we obtain the same results in both cases, the electromotive forces and the resistances being increased by an equal amount, for

$$\frac{E}{R} = \frac{nE}{nR}.$$

The resistance R includes the resistance of the wires, the liquid exterior to the battery, should such be included in the circuit, and the resistance of the liquid and metals of the battery itself. As regards the resistance of the battery, it is found to decrease in exact proportion as the surface is increased, and as regards the wire, its resistance is directly as its length and inversely proportional to its section.

Let the whole resistance be denoted by R, as before, the resistance of the battery by B, and that of the wire by W; then, supposing no other obstacle to be included in the circuit,

$$R = B + W.$$

But B varies *directly* as the distance between the plates, which may be expressed by d, and *inversely* as the surface of plates, which may be expressed by s, so that

$$B = \frac{d}{s}.$$

Again, W varies directly as the length of the wire and inversely as the area of its section; it may, therefore, be expressed by $\frac{l}{s}$, l being the length of the wire, and s its section. If, therefore,

we substitute these values for W and B in the formula for F, we get

$$F = \frac{E}{\frac{d}{s} + \frac{l}{s'}}.$$

Hence it appears that the force of the current may be increased in four ways:—1. by increasing the thickness of the wire; 2. by diminishing its length; 3. by increasing the surface of the plates of the voltaic elements, or diminishing the distance between them; and 4. by employing more energetic elements.

The above formula enables us to calculate the effect of changing the length or thickness of the conducting wire, or of varying the size and distance apart of the plates of a voltaic pair, provided there is no alteration in *kind* of conducting wire, or in the battery. But both may vary; and in this case other symbols must be introduced which may be replaced by the real quantities which they denote as determined by experiment. Let the resistance of the particular liquid used be denoted by A, and the specific resistance of the kind of metal forming the circuit by m, then

$$F = \frac{E}{\frac{A\,d}{s} + \frac{m\,l}{s}}.$$

The resistances of different metals are inversely as their conducting powers, the latest determination of which is by Matthiessen whose results are expressed in the following table (*Phil. Trans.*, 1858 and 1862, and *Proceed. Roy. Soc.*, vol. xii. p. 472):—

METAL—PURE	Conductivity		Conductivity at 212°		
	Silver at 32° = 100		Silver at 212° = 100	Each metal compared with itself at 32° = 100	
	At 32°	At 212°			loss per ct.
Silver (hard drawn) . .	100·00	71·56	100·00	71·56	28·44
Copper (hard drawn) . .	99·95	70·27	98·20	70·31	29·69
Gold (hard drawn) . .	77·96	55·90	78·11	71·70	28·30
Zinc	29·02	20·67	28·89	71·23	28·77
Cadmium	23·72	16·77	23·44	70·70	29·30
Cobalt	17·22				
Iron (hard drawn) . .	16·81				
Nickel	13·11				
Tin	12·36	8·67	12·12	70·11	29·89
Thallium	9·16			68·58	31·42
Lead	8·32	5·86	8·18	70·39	29·61
Arsenicum	4·76	3·33	4·65	69·88	30·12
Antimony	4·62	3·26	4·55	70·54	29·46
Bismuth	1·245	0·878	1·227	70·51	29·69

It is thus seen that a similar thickness of *iron* wire would enfeeble a current of electricity much more than one of copper, and that, to get with the same length of wire as strong a current from a given battery by means of an iron wire and a copper wire, it would be necessary to use an iron wire of greater section than that of copper, in the ratio of 99·95 to 16·81, or nearly six times as great, which, if the wires were round, would give a diameter nearly $2\frac{1}{2}$ times as great.

(109) **Application of Ohm's Theory to Compound Voltaic Circles.**—As each pair of elements contributes its own electromotive force to the current, it is evident that the whole electromotive force will be proportional to the number of pairs, provided they are all equal. Denoting the number of pairs by n, then the whole electromotive force will be n E, E representing that of a single pair. But though the electromotive power is n times as strong, the resistance is at the same time increased n times, the current having now to traverse the whole liquid of the several pairs of elements ; consequently the current will not be n times as forcible, and the formula for the force of the current will be

$$F = \frac{n\,E}{\frac{n\,A\,d}{s} + \frac{m\,l}{s}}.$$

This formula will serve in all cases to determine the force of a battery of any number of pairs where the force of a single pair and the length of the conducting wire are given, and leads to the following general law (*Wheatstone, Phil. Trans.*, 1843) :—

1. The electromotive force of a voltaic current varies with the number of the elements and with the nature of the metals and liquids which constitute each element, but is in no degree dependent on the dimensions of any of their parts.

2. The resistance of each element is directly proportional to the distances of the plates from each other in the liquid, and to the specific resistance of the liquid, and is also inversely proportional to the surface of the plates in contact with the liquid.

3. The resistance of the connecting wire of the circuit is directly proportional to its length, and to its specific resistance, and inversely proportional to its section.

When the conducting wire is composed of different thicknesses, or of different metals joined together, it is found that the force of the current is everywhere the same. It is found convenient to refer all resistance of wires or liquids or other matters through which the current has to pass to certain definite equivalents or specific standards. This is generally taken at so many units of length of a standard copper wire of specified thickness. The length

of this wire, or the number of units of length of it which afford the same resistance as any conductor, is called *the reduced length* of that conductor.

If we represent the length, conducting power, and section of the substance forming the circuit by l, c, and s, and the reduced length, or equivalent length, of the standard wire by l', and its conducting power and section by c' and s', then, as the force in each case is represented by

$$f = \frac{c\,s}{l} \text{ and } f' = \frac{c'\,s'}{l'},$$

and it is required that the force of the current given by the one is to be equal to that given by the other, we must have

$$f = f'\,;\ \text{or } \frac{c\,s}{l} = \frac{c'\,s'}{l'}\,;\ \text{or } l = \frac{c'\,s'\,l'}{c\,s}.$$

(110) **Wheatstone's Parallelogram or Bridge.**—For measuring the electrical resistance of a metal as compared with a given standard, the instrument shown in Fig. 148 was invented by Wheatstone.

1. *Construction of the Bridge.*—N A P C is a mahogany board supported on levelling screws, and provided with a binding screw in the centre of each side; these screws are connected by a thick copper wire, W W W W, let into a groove in the surface of the board, and forming a parallelogram, N A P C. At points exactly equidistant from the angle N, the wires N C, N A are severed, and the ends are connected with binding screws, $s\ s$, $s'\ s'$. Similarly, the wires, P A, P C are severed, and the ends connected with the binding screws $r\ r$, $r'\ r'$. In the centre of the board is a galvanometer, having a compound needle suspended by a fibre of raw silk in the centre of a coil of moderately thick wire. This coil is attached to a disc, A, movable on a vertical axis, and a graduated card is fixed on the top of the coils, on which the deflection of the needle may be observed; a piece of talc is cemented to the card at 90° to check the violent oscillations of the needle.

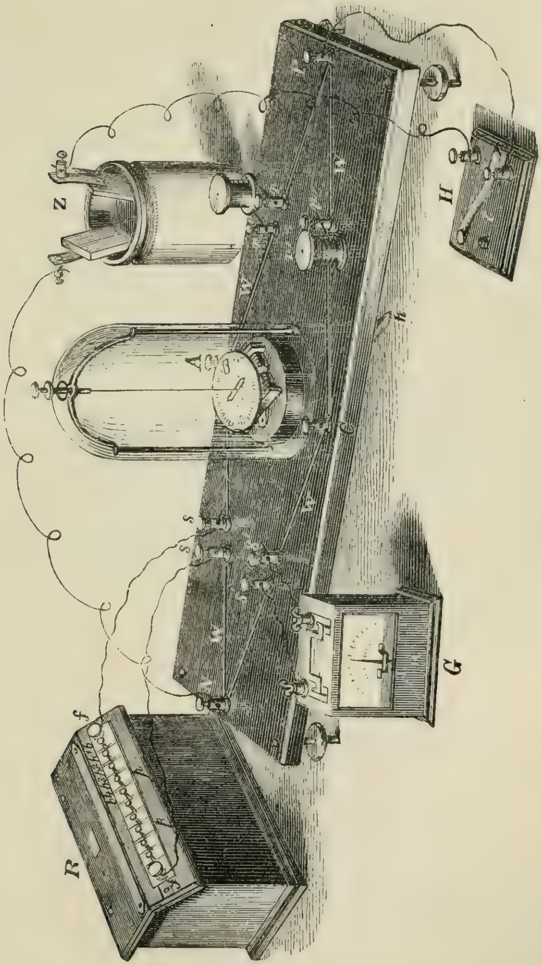
The ends of the coil are connected with the terminals C and A by wires sufficiently long to allow of the graduated disc and coils being moved round by the handle h, so as to bring the zero point to correspond with the needle when it is in the plane of the magnetic meridian. A single cell of the Smee or Daniell battery is generally sufficient to work the instrument; it is shown at Z, one pole being in connection with N, the other, through the intervention of a contact maker, with P.

2. *Action of the Instrument.*—Suppose the wire W to be unbroken at $r\ r'$, $s\ s'$; when contact is made at H, a current passes from Z to N, where it bifurcates, and as the two wires N A P, N C P offer equal resistances, one-half of the current passes through each channel, the currents reunite at P, and pass to Z, completing the circuit.

Neglecting the resistance of the external connections between Z and N, and Z and P, which do not influence the result: if the electrical tension at N be represented by 10, at P it will be 0, and at A and C it will be 5; hence there will be no current between C and A, and the galvanometer will be unaffected. If now a resistance of *one* mile be introduced at s, and an equi-

valent resistance at *s*′, the current will bifurcate equally as before, but the tension at N, *s*′, and *s* will be much increased, and that at C and A will

Fig. 148.



diminish proportionately; but being still equal on both sides, no current will pass from C to A, and the needle of the galvanometer will remain at rest.

If, however, the resistance introduced at s s be either less or greater than the resistance interposed between s' s', the current will no longer divide itself equally at N; the distribution of the tensions in N A P and N C P will no longer be similar, the tension at C will be different from the tension at A, and an electric current will be established between C and A, causing a deflection of the needle of the galvanometer, and the direction of the deflection will denote on which side the resistance is greatest.

3. *General Law of the Instrument.*—The conductors N A P and N C P being united at N and P, the relations between the electric tensions at N and P must always be the same for both conductors, however the resistances of the conductors and the tensions may be varied. Hence the electric tensions at A and C will be equal as long as the following proportional resistances are maintained, N A : A P : : N C : C P, and as long as the electric tensions at C and A are identical, no current will pass between them through the galvanometer.

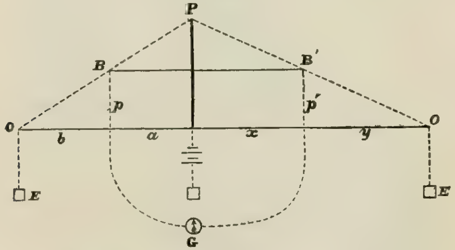
If now there is introduced into the circuit on one side of the parallelogram a conductor having an *unknown* resistance, we can determine its resistance by introducing known resistances into the circuit on the one side until, the galvanometer being no longer affected, we know that the current is equally divided, and that the resistances on both sides are equal.

The mode of varying the resistance is by means of *rheostats* and *resistance coils*, the former being used for comparatively small and the latter for considerable resistances; both instruments are the inventions of Professor Wheatstone. The parallelogram is extensively used in testing the conductivity of the copper wire to be used for submarine cables.

Wheatstone's Bridge.—The following geometrical explanation of Wheatstone's bridge will undoubtedly be found an useful assistance to the description already given:—

Draw the line (Fig. 149) from O to o, representing in one line the four arms of a bridge; both ends being to earth, potential is therefore O, and

Fig. 149.



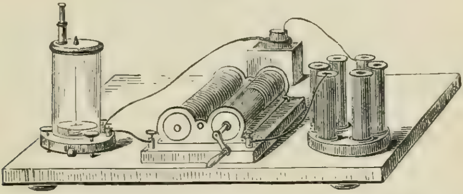
consequently the line would represent a continuous circuit. At any point attach one pole of a source (whose other extremity is to *earth*); the vertical P will represent the potential at that point, and the dotted lines the potential at every other point. Let now p represent the potential at any point in $b\,a$, then draw B B′ parallel to O o and p' from B′ at right angles to $x\,y$; then $p' = p$. If these two points be joined together through a galvanometer, their potential being equal no current will pass.

(111) **Wheatstone's Rheostat and Resistance Coils.**—In their verifications of Ohm's law, the German and French electricians first observed the oscillations of the needle of the galvanometer when no extraneous resistance was introduced into the circuit; they then added a known resistance, and again measured the oscillations. Wheatstone adopted a different method: instead of *constant* he employed variable resistances, bringing thereby the currents compared to equality, and inferring, from the amount of resistance measured out between two deviations of the galvanometer needle, the electromotive forces and resistances of the circuit, according to the particular conditions of the experiments.

For this purpose, he invented an instrument, which he calls a *rheostat*.

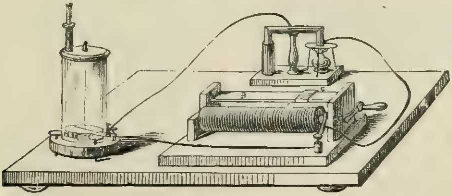
It consists essentially of two cylinders (Figs. 150 and 151), one of wood, on which a spiral groove is cut, and round which is coiled a long wire of

Fig. 150.



very small diameter; the other is made of brass. By means of a handle any part of the wire can be unwound from the wooden cylinder and wound on the brass. The coils on the wood cylinder being insulated and kept separate from each other by the groove, the current passes through the

Fig. 151



entire length of the wire coiled upon that cylinder; but the coils on the brass cylinder not being insulated, the current passes immediately from the point of the wire which is in contact with the cylinder to a spring in metallic communication with the wires of the circuit. The effective part of the length of the wire is therefore the variable portion which is on the wooden cylinder.

The cylinders are six inches in length and $1\frac{1}{2}$ inch in diameter; the threads

of the screw are 40 to the inch, and the wire is of brass $\frac{1}{100}$ of an inch in diameter. A scale is placed to measure the number of coils unwound; and the fractions of a coil are determined by an index which is fixed to the axis of one of the cylinders, and points to the divisions of a graduated scale.

For measuring very great resistances, such as long telegraph wires or imperfectly conducting liquids, a series of coils of fine silk-covered copper wire, about $\frac{1}{200}$ of an inch in diameter, is employed. Two of these coils are 50 feet in length; the others are respectively 100, 200, 400, and 800 feet. The two ends of each coil are attached to short thick wires, fixed to the upper faces of the cylinders, which serve to combine all the coils in one continuous length. On the upper face of each cylinder is a double brass spring, movable round a centre, so that its ends may rest at pleasure, either on the ends of the thick wires united to the circuit, or may be removed from them and rest upon the wood. In the latter position, the current from the circuit must pass through the coil; but in the former position, it passes through the spring, and removes the entire resistance of the coil from the circuit. When all the springs rest on the wires, the resistance of the whole series of coils is removed; but by turning the springs so as to introduce different coils into the circuit, any multiple of 50 feet up to 1600 may be brought into it.

For measuring small resistances, Wheatstone employs a cylinder $10\frac{1}{2}$ inches in length, and $3\frac{1}{4}$ inches in diameter, round which is wound 108 coils of copper wire $\frac{1}{16}$ of an inch thick, any part of which can, by turning the cylinder, be brought into the circuit.

In order to determine the sum of the electromotive forces in a voltaic circuit, Wheatstone proceeds as follows (*Phil. Trans.*, 1843, p. 313):—

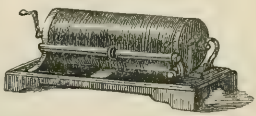
'In two circuits producing equal electromotive effects, the sum of the electromotive forces, divided by the sum of the resistances, is a constant quantity, i.e. $\frac{E}{R}=\frac{nE}{nR}$; if E and R be proportionately increased or diminished, F will obviously remain unchanged. Knowing, therefore, the proportion of resistances in two circuits producing the same effect, we are enabled immediately to infer that of the electromotive forces. But as it is difficult in many cases to determine the total resistance, consisting of the partial resistances of the *rheomotor* (or voltaic combination) itself, the galvanometer, the *rheostat*, &c., I have recourse to the following simple process. Increasing the resistance of the first circuit by a known quantity, r, the expression becomes $\frac{E}{R+r}$. In order that the effect in the second circuit shall be rendered equal to this, it is evident that one added resistance must be multiplied by the same factor as that by which the electromotive forces and the original resistances are multiplied, for $\frac{E}{R+r}=\frac{nE}{nR+nr}$. The relations of the length of

the added resistances r and nr, which are known, immediately give therefore those of the electromotive forces.'

Example.—Let it be required to determine the relative electromotive forces in a single pair, and two similar pairs of Daniell's sulphate of copper battery. Introduce first the rheostat and the galvanometer (Fig. 151) into the circuit of the single cell, and adjust the wire of the coil either by coiling or uncoiling, as the case may be, until the galvanometer needle stands at 45°; then uncoil the wire until the needle is reduced to 40°; and the number of turns required to do this represents the electromotive force of the cell. Suppose this number to be 35. Next operate precisely in the same manner with the two cells, interposing, if necessary, one or more of the resistance coil. The number of turns of the rheostat cylinder required to bring the needle of the galvanometer to 40° will now be found to be 70—just double the number required with the single cell. The electromotive forces in the two batteries are therefore as 1 : 2. If in the second experiment the two cells of the battery are arranged as a single pair—that is, the copper of one connected with the copper of the other, and the zinc plate of one with the zinc of the other—it will be found that, though it requires a greater interposed resistance to bring the needle of the galvanometer to 45°, the same number of subsequent turns will be required as before to reduce it to 35°, thus showing that by increasing the size of the plates the electromotive force of the battery is not increased.

To obviate the inconvenience of winding and unwinding the wire, whereby it is apt to become loose on the cylinder, and one turn to ride on another, the rheostat has been differently arranged by Mr. Becker. In his form of the instrument, the wire is wound permanently on an insulating cylinder, and any number of turns are introduced into the circuit by means of a grooved wheel, w (Fig. 152), moving on a graduated bar, *a a*. When the cylinder is made to rotate, the wheel is screwed along the bar, or the bar may be pressed back by hand, and the wheel slipped along it to any point desired.

Fig. 152.



(112) **Standards of Resistance.**—The standard of resistance adopted by Wheatstone was that produced by a copper wire, one foot of which weighs 100 grains. Varley's 'unit,' at one time adopted by the Electric Telegraph Company, is one mile of the wire used for underground work and for tunnels (No. 16 copper wire). German-silver wire is now generally used for resistance

coils, because its conductivity is but little affected by change of temperature when compared with pure copper. Siemens and Halske exhibited at the International Exhibition of 1862 a resistance coil based on an unit expressing the resistance of a metre of mercury of one millimetre section, at the temperature of melting ice. Other coils have been constructed to represent the resistance of a thousand metres of iron wire four millimetres in diameter, such as is used in telegraphic lines abroad. Dr. Matthiessen has adjusted a coil expressing the resistance of a standard mile of chemically pure copper wire one-sixteenth of an inch in diameter, at the temperature of $15^{\circ}\cdot5$ centigrade. This resistance is very different from that of a mile of any commercial copper, and the various commercial coppers differ too widely from each other to allow any approximate ratio to be named between them and pure copper. The specific resistance, however, of copper selected for telegraphic cables is generally about 20 per cent. higher than that of pure copper.

(113) **Weber and Thomson's Absolute Electro-magnetic Measure.**—The value to electrical science of an universal standard or unit of resistance would be very great, and, if generally adopted, the results of independent observers all over the world would become comparable, and vague expressions of opinion would be replaced by definite measurements. Weber and Thomson have proposed a system for the expression of those quantities in absolute units chosen with reference to their relations with each other, and with the units of force and work, which must henceforth be looked upon as the connecting link between all physical measurements. The leading idea of this system is expressed as follows by Mr. Fleeming Jenkin (*Jurors' Report on Electrical Instruments, International Exhibition*, 1862):—

'A battery or other rheomotor of unit electromotive force will generate a current of unit strength in a circuit of unit resistance, and in the unit of time will convey a unit quantity of electricity through this circuit, doing in the same time a unit of work or its equivalent. These relations leave the absolute magnitude of the series of standards undetermined. Weber has proposed to fix the series in various ways; but the most convenient (where measurements have to be made by observations conducted with the aid of magnets) is probably that in which the series is fixed by the definition of the unit current, as that current the unit length of which at a unit distance exerts a unit force on the unit magnetic pole. The definition of the unit magnetic pole proposed by Gauss and Weber in its turn depends solely on the units of mass, time, and length.'

In determining the unit of electrical resistance and the other electrical units, we must simply follow the natural relations exist-

ing between the various electrical quantities and between these and the fundamental units of *time, mass,* and *space.*

In the absolute electro-magnetic system of Weber and Thomson the following equations exist between the mechanical and electrical units (*Jenkin, Proc. Royal Soc.*, vol. xiv. p. 158):—

$$W = C^2Rt \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where W is the work done in the time t by the current C conveyed through a conductor of the resistance R. This equation expresses Joule and Thomson's law,

$$C = \frac{E}{R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where E is the electromotive force. This equation expresses Ohm's law,

$$Q = Ct \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

which again expresses a relation first proved by Faraday, where Q is the quantity of electricity conveyed or neutralised by the current in the time t. Finally, the whole system is rendered determinate by the conditions that the unit length of the unit current must produce the unit force on the unit pole (Gauss) at the unit distance. If it is preferred to omit the conceptions of magnetism, this last statement is exactly equivalent to saying that the unit current conducted round two circles of unit area in vertical planes at right angles to each other, one circuit being at a great distance, D, above the other, will cause a couple to act between the circuits of a magnitude equal to the reciprocal cube of the distance D. This last relation expresses the proposal made by Weber for connecting the electric and magnetic measure.

These four relations serve to define the four magnitudes R, C, Q, and E, without reference to any but the fundamental units of time, space, and mass; and when reduced to these fundamental units, it will be found that the measurement of R involves simply a velocity, i.e. the quotient of a length by a time. It is for this reason that the absolute measure of resistance is styled $\frac{\text{metre}}{\text{second}}$ or $\frac{\text{foot}}{\text{second}}$, precisely as the common non-absolute unit of work involving the product of a weight into a length is styled kilogramme or foot pound.

It is difficult to give a popular definition of the unit; but the following by Fleeming Jenkin will serve to show how a real velocity may be used to measure a resistance by using the velocity with which under certain circumstances part of a circuit must be

made to move in order to induce a given current in a circuit of the resistance to be measured:—

The resistance of the absolute $\frac{\text{metre}}{\text{second}}$ is such that a current generated in a circuit of that resistance by the electro-magnetic force due to a straight bar 1 metre long, moving across a magnetic field of unit intensity, perpendicularly to the lines of force, and to its own direction, with a velocity of 1 metre per second, would, if doing no other work or equivalent of work, develop in that circuit in one second of time a total amount of heat equivalent to one absolute unit of work, or sufficient heat, according to Joule's experiments, to heat 0·0002405 gramme of water at its maximum density 1° C.

The relations of the system of units, called by Weber the electro-magnetic units, to each other and to the mechanical units, may be summed up thus:—

The unit of a current conveys a unit of electricity through the circuit in a unit of time. The unit current in a conductor of unit resistance produces an effect equivalent to the unit of work in one unit of time. The unit current will be produced in a circuit of unit resistance by the unit of electro-magnetic force. The unit current flowing through a conductor unit of length will exert the unit force on the unit pole at the unit distance.

In order to determine the resistance of a wire in absolute measure, Weber (*Phil. Mag.* 1861) employed two methods.

1. By suddenly turning a coil of wire about an axis so as to alter its position relatively to the terrestrial lines of magnetic force, he produced an electromotive force acting for a short time in the coil. This coil was connected with another fixed coil having a magnet suspended in its centre. The current generated by the electromotive force passed through both coils, and gave the magnet a sudden impulse, the amount of which was measured by its extreme deflection.

Thus an electromotive force of short duration produced a current of short duration. The total amount of electromotive force depended on the size of the movable coil, and the intensity of terrestrial magnetism. The total amount of the current is measured by the impulse given to the magnet, and the mechanical value of the impulse is measured by the angle through which it swings. The resistance of the whole circuit, consisting of both coils, is then ascertained by dividing the electromotive force by the current.

2. By causing a powerful magnet to oscillate within a coil of wire. By the motion of the magnet currents are produced in the coil, and these reacting on the magnet retard its motion. The rate of diminution of the amplitude of the oscillations, when compared with the rate of diminution when the current is broken, affords the means of determining the resistance of the circuit.

(114) **The British Association Unit of Electrical Resistance.**—In their experimental measurements of electrical resistance, Messrs. J. Clerk Maxwell, Balfour Stewart, and Fleeming Jenkin (*On Standards of Electrical Resistance, British Association Report for* 1863) adopted an apparatus designed by Professor Thomson, by which the resistance of a coil can be determined in electromagnetic measure by the observation of the constant deflection of a magnet.

The coil of wire is made to revolve about a vertical diameter with constant velocity. The motion of the coil among the lines of force, due to the earth's magnetism, produces indirect currents in the coil, which are alternately in opposite direction with respect to the coil itself, the direction changing as the plane of the coil passes through the east and west direction. If we consider the direction of the current with respect to a fixed line in the east and west direction, we shall find that the changes in the current are accompanied with changes on the face of the coil presented to the east, so that the absolute direction of the current as seen from the east remains always the same.

If a magnet be suspended in the centre of the coil, it will be deflected from the north and south line by the action of these currents, and will be turned in the same direction as the coil revolves. The force producing this deflection is varying continually in magnitude and direction; but as the periodic time is small, the oscillations of the magnet may be rendered insensible, by increasing the mass of the apparatus along which it is suspended. The resistance of the coil may be found when we know the dimensions of the coil, the velocity of rotation, and the deflection of the magnet. The intensity of terrestrial magnetism enters into the measurement of the electromotive force, and also into the measurement of the current; but the measure of the resistance, which is the ratio of these two quantities, is quite independent of the value of the magnetic intensity.

For a description of the apparatus, and for a detail of the experiments made with it, and a discussion of the results, we must refer to the report above alluded to. The committee are now prepared to supply the public with copies of their standard of electrical resistance, constructed of an alloy of platinum and silver, which are close approximations to 10,000,000 $\frac{\text{metre}}{\text{seconds}}$ in Weber's absolute electro-magnetic system, the magnitude $\frac{\text{metre}}{\text{seconds}}$ being far too small to be practically convenient. This is not very different from Siemens's mercury unit, which has been found convenient in practice. It is about the 25th part of one mile of No. 16 impure copper wire, used as a standard by the Electric and International Company. It is decided that the new standard shall not be called 'absolute measure,' or described as so many $\frac{\text{metre}}{\text{seconds}}$, but that it shall receive a distinctive name, such as the B. A. unit, or, as Mr. Latimer

Clark suggests, the 'Ohmad' or 'Ohm.' Under the name of 'Ohm' the British Association unit of resistance is now generally known, that expression having been universally adopted as the name for the general standard. A 'Megohm' is the equivalent of one million 'Ohms.'

CHAPTER X.

VOLTAIC ELECTRICITY (*continued*).

THE CHEMICAL POWERS OF THE VOLTAIC PILE.

Decomposition of Water and Saline Solutions—Hypothesis of Grotthus—Faraday's Researches—Secondary Results—Electro-metallurgy—Electro-plating—Daniell's Researches—Electrical Endosmose.

The chemical powers of the voltaic pile were discovered and described by Messrs. Nicholson and Carlisle in the year 1800. Water was the first compound decomposed.

In the year 1806 Davy delivered before the Royal Society his celebrated lecture, 'On some Chemical Agencies of Electricity;' and in 1807 he announced the grand discovery of the decomposition of the fixed alkalies.

The masterly researches of Faraday were given to the world between the years 1831 and 1840.

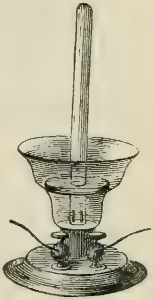
When water and certain saline solutions are made part of the electric circuit, so that a current of electricity may pass through them, they are decomposed—that is, they yield up their elements, in obedience to certain laws. Water is resolved into oxygen and hydrogen gases, and the acid and alkaline matters of the neutral salts, which it holds in solution, are separated *not* in an indiscriminate manner, but the oxygen and the acids are all developed at the positive pole,[1] and the hydrogen and the alkalies at the nega-

[1] According to Faraday's views, the determining force is not at the so-called *poles* of the voltaic battery, but *within* the body suffering decomposition. The poles of the battery he regards as the *doors* through which the electricity enters into, or passes out of, the decomposing body; he proposes, therefore, for them the name *electrodes*, from ἤλεκτρον and ὁδὸς (way). Compounds decomposable by the electric current he proposes to call *electrolytes*, from ἤλεκτρον and λύω (set free); and the act of decomposing a compound electro-chemically he calls its *electrolysis*. Mr. Daniell distinguishes the 'doors' through which the current enters and departs by the terms *zincode* and *platinode*, the former being the plate which occupies the position of the

tive. If *pure* water be submitted to the action of the current, it is decomposed with great difficulty, in consequence, probably, of its bad conducting power; for, if a little sulphuric acid be added, it yields to the power of a very moderate current.

To decompose acidulated water, it may be confined in a glass tube, sealed hermetically at one end, and made part of the circuit by means of gold or platinum wires; or the arrangement shown in Fig. 153 may be adopted, the wires being about one-fourth of an inch apart. If two tubes be employed, one placed over either wire, gas will be collected in each; but that in the tube over the negative *electrode* will be rather more than double in volume to that in the tube over the positive *electrode*; the former being hydrogen, and the latter oxygen gas. Now in vapour of water, the relation in volume between the hydrogen and oxygen gases is exactly as two to one; and the reason why they do not appear precisely in this proportion when water is *electrolised* is because oxygen is partially soluble, and a portion is therefore retained in the acidulated water over which the gases are collected.

Fig. 153.



To show the decomposition of a neutral salt, and the determination of the acid, or the element replacing it, to the positive electrode, and of the alkali to the negative, the following experiments may be made:—

1. A small quantity of sulphate of soda may be dissolved in water tinged blue by tincture of violets, and introduced into a glass syphon-shaped tube, into either aperture of which is inserted a platinum wire or plate proceeding from the terminals of a voltaic battery, as shown in Fig. 154; in a short time the fluid in the limb into which the positive electrode is placed will become *red*, and that in the limb into which the negative electrode is inserted will become *green*; the former indicating the presence of *acid*, and the latter of *alkali*. If the direction of the current be reversed, the colours will be gradually reversed also.

This experiment may be modified thus:—

Let two tubes, each furnished with a platinum electrode, be filled with the coloured saline solution, and placed in two separate glasses, connected together by a glass syphon-shaped tube, likewise filled with the saline solution, as shown in Fig. 155. On transmitting the current, it will be found that, not-

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generating plate on the battery, and the latter that of the conducting plate. The old terms positive and negative pole, or positive and negative electrode, are, however, almost universally used.

withstanding they are inverted in separate glasses, the liquid in P will be turned *red*, and that in N *green*, as before; and, if the experiment be continued sufficiently long, the alkali of the salt will be found to have passed from P to N, and the acid from N to P; the acid and alkali appearing to traverse the syphon in opposite directions, and the usual chemical affinities appearing to be suspended under the influence of electrical attraction.

Fig. 154.

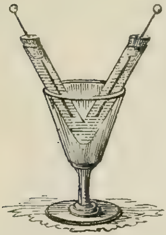
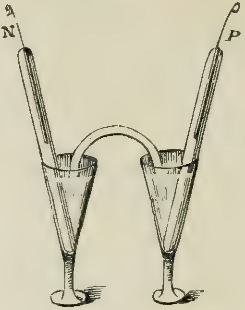
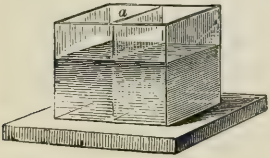


Fig. 155.



2. A solution of common salt in water acidulated with hydrochloric acid, and coloured blue with a few drops of the sulphuric solution of indigo, may be introduced into a glass cell, divided into two compartments by a diaphragm composed of two or three folds of bibulous paper (Fig. 156). On transmitting a voltaic current through the solution, it will be found in a few minutes that the compartment in which the *positive* electrode is immersed has lost its colour, while the liquid in the other compartment is unaltered; but on reversing the direction of the current, the liquid in this compartment will also be discoloured. In this experiment *chlorine* is eliminated at the positive electrode and hydrogen at the negative; the former element possessing the property of bleaching indigo.

Fig. 156.



3. Let the cell be filled with a weak solution of starch acidified with hydrochloric acid, and a few drops of *iodide of potassium* added. Then, after dividing the cell by a diaphragm of bibulous paper, let the voltaic current be transmitted as before. The liquid in the positive compartment will speedily become blue, owing to the liberation there of *iodine*, which, entering immediately into combination with the starch, forms an iodide of starch of a fine blue colour.

4. Let the cell be filled with solution of salt, to which a few drops of solution of *ferrocyanide of potassium* have been added. Introduce into each compartment a plate of *iron* as an electrode; in a few minutes the liquid in the *positive* compartment will become of a deep blue colour, in consequence of

the oxidation and solution there of the iron, and the consequent formation of *prussian blue* by reaction with the solution of the ferrocyanide.

5. Fill a tall cylinder with a moderately strong solution of sulphate of copper; connect a long platinum slip with either end of a voltaic battery, and immerse them in the solution. In a few seconds the plate connected with the *negative* electrode will become covered with metallic copper, that in connection with the *positive* electrode remaining bright. Reverse the direction of the current, the metallic cupreous deposit will gradually vanish from the platinum plate, and make its appearance on the other plate, now the *negative* electrode. In the electrolysis of metallic solutions, the metals, when reduced, always appear at the negative electrode.

A remarkable paper on *Some Chemical Agencies of Electricity* was communicated to the Royal Society in November 1806 by Davy. Amongst other experiments the following are described:—

'An arrangement was made consisting of three vessels, as shown in Fig. 157. Solution of *sulphate of potash* was placed in contact with the negatively electrified point, pure *water* was placed in contact with the positively electrified point, and a weak solution of *ammonia* was made the middle link of the conducting chain, so that no sulphuric acid could pass to the positive point in the distilled water without passing through the solution of ammonia; the three glasses were connected together by pieces of amianthus. A power of 150 pairs was used. In less than five minutes it was found by litmus paper that acid was collecting round the positive point; in half an hour the result was sufficiently distinct for accurate examination. The water was sour to the taste, and precipitated solution of nitrate of barytes. . . . . . . Muriatic acid from muriate of soda and nitric acid from nitrate of potash were transmitted through concentrated alkaline menstrua under similar circumstances; when distilled water was placed in the negative part of the circuit, a solution of sulphuric, muriatic, or nitric acid in the middle, and any neutral salt with the base of *lime, soda, potash, ammonia*, or *magnesia* in the positive part, the alkaline matter was transmitted through the acid matter to the negative surface, with similar circumstances to those occurring during the passage of the acid through alkaline menstrua.'

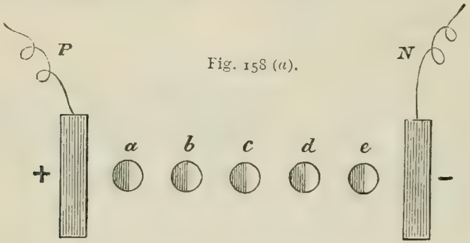
Fig. 157.

These experiments excited at the time they were announced the utmost astonishment; and the only way by which they could at all be explained was by supposing that throughout the whole circuit the natural affinities of substances are suspended, but again recovered when they are dismissed at the electrodes by which they were attracted.

(115) **Hypothesis of Grotthus.**—The earliest and most plausible theory to explain the chemical decompositions effected by the voltaic battery was that of Grotthus. He assumed that each

constituent of a binary compound is in an opposite electrical state, one of the elements being electro-positive, and the other electro-negative; and that under the influence of the contrary electricities of the poles or electrodes there is effected in the liquid in which they are immersed a series of decompositions and recompositions from pole to pole. Take for example the case of water. In its natural or unelectrified state the natural electricities of the molecules of oxygen and hydrogen are in equilibrium, as they each possess an exactly equal amount of the opposite forces, the oxygen being electro-negative—that is, having a natural attraction for negative electricity—and the hydrogen electro-positive, i.e. having a natural attraction for positive electricity. When brought under the influence of the voltaic current, the row of molecules between the poles or electrodes is thrown first into an electro-polar state—

Fig. 158 (*a*).



that is, the electro-negative molecules turn towards the positive electrode, and the electro-positive molecules turn towards the negative electrode, as shown in Fig. 158 (*a*), where the dark half-circles represent the molecules of electro-negative oxygen, and the light half-circles those of electro-positive hydrogen.

The positive electrode P acts by induction on the electricity of the molecule of water *a*; the oxygen takes a negative charge, and turns towards the positive electrode. In like manner the negative electrode N acts by induction on the electricity of the molecule *e*, the hydrogen of which takes a positive charge, and turns towards the negative electrode. The positive electricity of *a* thus accumulated on the hydrogen molecule produces the same action on *b* as the positive electrode produced on it; *b* in like manner acts upon *c*; *c* on *d*, and so on, until all the particles of water between the two electrodes assume the polar arrangement shown in the figure. If now the voltaic current be sufficiently powerful, discharge takes place along the whole line of particles, the oxygen of each molecule passing on to the hydrogen of the one on its left; consequently a molecule of oxygen is left free, and escapes as gas at the positive

electrode, and a molecule of hydrogen is left free, and escapes as gas at the negative, thus:—

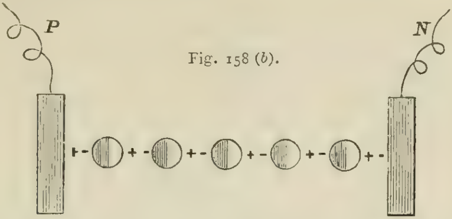


Fig. 158 (*b*).

The same theory is applicable to every case of the decomposition of a single electrolyte, and also to the wonderful experiments of Davy. In all cases there must be one unbroken series of particles of the electrolyte between the two electrodes; and in the case in which the acid and alkaline constituents of the salts appear to be drawn through pure water, ammonia, &c., the decomposition could not have commenced until a portion of the salt had passed by capillary attraction across the syphons, so that a continuous line of saline particles was established between the electrodes.

(116) **Water may serve as an Electrode.**—A substance cannot be transferred in the electric current beyond the point where it ceases to find a particle with which it can combine. A single *iön*[1]—that is, one not in combination with another—will have no tendency to pass to either electrode, and will be perfectly indifferent to the passing current. If combined in right proportions with another *iön* strongly opposed to it in ordinary chemical relations—that is, if an *aniön* be combined with a *catiön*—then *both* will travel, the one to the *anode*, and the other to the *cathode*. If, therefore, an *iön* pass towards one of the electrodes, another *iön* must be also passing simultaneously to the other electrode, though from secondary action it may not make its appearance. The nature of the substance of which the electrode is formed, provided it be a conductor, causes no difference in the electro-chemical decomposition, either in kind or degree, though by secondary action it may greatly influence the state in which the *iöns* finally appear.

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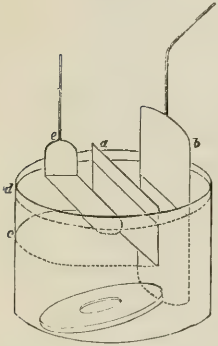
[1] Faraday proposes to call the elements of an electrolyte *iöns*, from ἰών, participle of the verb εἶμι (to go). The *iöns* which make their appearance at the positive electrode, or *anode*, he calls *aniöns*; the term *anode* being derived from ἄνα (upwards), and ὁδὸς (way)—*the way which the sun rises*; the *iöns* which make their appearance at the negative electrode, or *cathode*, he calls *catiöns*; the term *cathode* being derived from κατὰ (downwards), and ὁδὸς (way)—*the way which the sun sets.*

The beautiful experiments of Faraday, in which *air* was shown to act as a pole, have been referred to (36). By the following arrangement, the decomposition of sulphate of magnesia against a surface of water is satisfactorily demonstrated :—

A glass basin, four inches in diameter and four inches deep, had a division of *mica a* (Fig. 159) fixed across its upper part so as to descend one inch and a half below the edge and be perfectly water-tight at the sides. A plate of platinum *b*, three inches wide, was put into the basin on one side of the division *a*, and retained there by a glass block below, so that any gas produced by it in a future stage of the experiment should not ascend beyond the mica, and cause currents in the liquid on that side. A strong solution of sulphate of magnesia was carefully poured without splashing into the basin, until it rose a little above the lower edge of the mica division *a*, great care being taken that the glass or mica on the unoccupied or *c* side of the division in the figure should not be moistened by agitation of the solution above the level to which it rose. A thin piece of cork, well wetted in distilled water, was then carefully and lightly placed on the solution at the *c* side, and distilled water poured gently on it, until a stratum the eighth of an inch in thickness appeared over the sulphate of magnesia. All was then left for a few minutes, that any solution adhering to the cork might sink away from it, or be removed from the water on which it now floated, and then more distilled water was added in a similar manner until it reached nearly to the top of the glass. In this way solution of sulphate of magnesia occupied the lower part of the glass, as also the upper on the right side of the mica ; but on the left-hand side of the division, a stratum of water from *c* to *d*, one inch and a half in depth, reposed upon it. The two presented, when looked through horizontally, a comparatively definite plane of contact.

Fig. 159.



A second platinum pole *e* was arranged so as to be just under the surface of the water in a position nearly horizontal, a little inclination being given to it, that gas evolved during decomposition might escape. The part immersed was three inches and a half long by one inch wide ; and about seven inches of water intervened between it and the solution of sulphate of magnesia.

The latter pole *e* was now connected with the *negative* end of a strong voltaic battery, whilst the former pole *b* was connected with the *positive* end. Gas was evolved at both poles, but from the intervention of pure water the decomposition was very feeble compared to what the battery would have effected in a uniform solution. After a while (less than a minute), *magnesia* also appeared at the negative end. *It did not make its appearance at the negative metallic pole, but in the water* at the place where the solution and the water met ; and on looking at it horizontally, it could there be perceived lying in the water upon the solution, not rising more than the fourth of an

inch above the latter, whilst the water between it and the negative pole was perfectly clear. On continuing the action, the bubbles of hydrogen rising upwards from the negative pole impressed a circulating movement on the stratum of water, upwards in the middle and downwards at the side, which gradually gave an ascending form to the cloud of magnesia in the part just under the pole, having an appearance as if it were there attracted to it, but this was altogether an effect of the currents, and did not occur till long after the phenomena looked for were satisfactorily ascertained.

(117) **Transfer of Elements.**—No element or substance can be transferred or pass from pole to pole unless it be in chemical relation to some other element or substance tending to pass in the opposite direction, the effect being essentially due to the mutual relation of such particles. Thus, pulverised *charcoal* or sublimed *sulphur*, diffused through dilute sulphuric acid, exhibits no tendency to pass to the negative pole, neither do *spongy platinum* or *gold* precipitated by sulphate of iron: yet in these cases the attraction of cohesion is almost perfectly overcome; the particles are so small as to remain for hours in suspension, and are perfectly free to move by the slightest impulse towards either pole.

As an illustration of the transfer of elements, and their progress in opposite directions, parallel to the electric current, the decomposition of *chloride of silver* by silver-wire electrodes may be referred to. Upon fusing a portion of this compound on a piece of glass, and bringing the poles into contact with it, there is abundance of silver evolved at the *negative* electrode, and an equal quantity absorbed at the *positive*, for no chlorine is set free, and by careful management the negative wire may be drawn from the fused globules as the silver is reduced there, the latter serving as the continuation of the pole, until a wire or thread of revived silver five or six inches in length is produced. At the same time the silver at the positive electrode is rapidly dissolved by the chlorine which seizes upon it, so that the wire has to be continually advanced as it is melted away. The whole experiment includes the action of only two elements—*silver* and *chlorine*.

(118) **Electro-chemical Classification of Elements.**—The following arrangement, though not altogether derived from experiment, and therefore subject to correction and modification, is useful as indicating the electrical tendencies of a large number of bodies. In the list of negative substances, each element is to be considered as negative to all *below* and positive to all *above* it in the list, and the same applies to the list of positive substances. The elements are therefore negative or positive only in relation to each other. Thus supposing a compound of *oxygen* and *chlorine* to be electrolysed, the oxygen would go to the *positive* and the chlorine to the *negative* electrode; but if the compound were composed

of *chlorine* and *phosphorus*, then the chlorine would go to the positive, and the phosphorus to the negative electrode :—

I. Electro-negative Elements.	II. Electro-positive Elements.
Oxygen.	Potassium.
Sulphur.	Sodium.
Selenium.	Lithium.
Nitrogen.	Barium.
Fluorine.	Strontium.
Chlorine.	Calcium.
Bromine.	Magnesium.
Iodine.	Aluminum.
Phosphorus.	Uranium.
Arsenic.	Manganese.
Chromium.	Zinc.
Vanadium.	Iron.
Tungsten.	Nickel.
Boron.	Cobalt.
Carbon.	Cadmium.
Antimony.	Lead.
Tellurium.	Tin.
Titanium.	Bismuth.
Silicon.	Copper.
Hydrogen.	Silver.
	Mercury.
	Palladium.
	Platinum.
	Gold.

(119) **Definite Electro-chemical Action.**—This was one of the grand discoveries of Faraday. In the investigation of the question it was necessary to construct an instrument which should measure out the electricity passing through it, and which, being interposed in the course of the current used in any particular experiment, should serve at pleasure either as a *comparative standard* of effect, or as a positive measurer of the agent. Water acidulated with sulphuric acid was the electrolyte chosen, and Fig. 160 exhibits one of the forms of apparatus employed, to which Faraday gave the appropriate name of the *Voltameter* or the *Volta-electrometer* :—

d is a straight tube, closed at one extremity, and graduated ; through the sides near the open end the platinum wires *b b'* pass, being fused into the glass and connected with the platinum plates within. The tube is fitted by grinding into one mouth of a double-necked bottle, one-half or two-thirds filled with water acidulated with sulphuric acid. The tube is filled by inclining the bottle ; and when an electric current is passed through it, the gases evolved collect in the upper part of the tube, and displace the dilute acid, the stopper *c* being left open. When the graduated tube *a* is filled with the mixed gases, the electric current may be broken by removing the wires connected with *b b'*, the stopper *c* replaced, and the meter tube refilled

by properly inclining the instrument; a second measure of gas may then be connected on re-establishing the circuit, and so on. Many other forms may

Fig. 160.

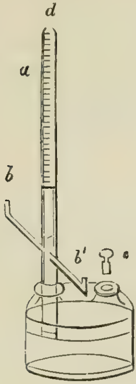
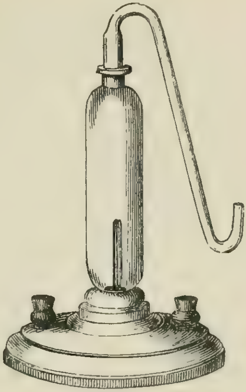


Fig. 161.



be given to this instrument. Fig. 161 is a useful arrangement, especially when the experiments are long continued, and where large quantities of the indicating gases are to be collected. The method of using it is sufficiently obvious. The delivery tube conducts the gases into a graduated receiver standing on the shelf of a hydro-pneumatic trough, where they can, from time to time, be measured.

By a series of experiments made with this apparatus under a variety of forms, with different-sized platinum electrodes, with acid solutions of various degrees of strength, and with currents of varying degrees of intensity, it was proved

'*That water when subjected to the influence of the electric current is decomposed in quantity exactly proportionate to the quantity of electricity which passes through it, whatever may be the conditions and circumstances under which it may be placed.*'

Hence the instrument may be employed with confidence as an exact measurer of voltaic electricity. As a proof that variation of *intensity* has no influence on the results if the *quantity* of electricity remain the same, Faraday arranged three voltameters in such a manner that after the current had passed through one it divided into *two* parts, each of which traversed one of the remaining instruments, and then reunited.

'*The sum of the decompositions in the two latter vessels was always equal to the decomposition in the former vessel.*'

To insure accurate results, the plates of the voltameter should

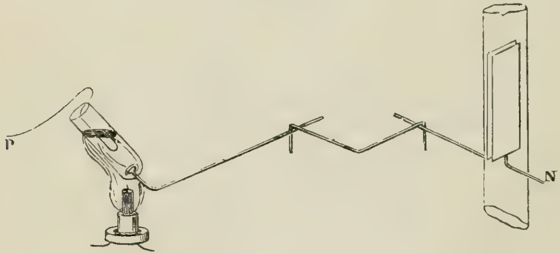
be placed very close to each other; and where more than one instrument is included in the circuit, the plates should be the same distance apart in each. The chance of solution of the gases in the acidulated water is thus diminished, and rendered uniform in each instrument. Still more accurate results are obtained by collecting the *hydrogen* only, as this gas is scarcely sensibly soluble in water.

'*When the same current passes successfully through different electrolytes, the quantities of these compounds decomposed, and of the several elements eliminated, are chemically equivalent to each other.*'

Example. Electrolytic Decomposition of Chloride of Tin.— Faraday made the following experiment :—

A piece of platinum wire had one extremity coiled into a small knob, and having been carefully weighed, was sealed hermetically into a piece of bottle-glass tube, so that the knob should be at the bottom of the tube within. The tube was suspended by a piece of platinum wire, so that the heat of a spirit-lamp could be applied to it. Recently fused protochloride of tin was introduced in sufficient quantity to occupy when melted about one-half of the tube. The wire of the tube was connected with the *negative* electrode of a voltaic battery, and a platinum wire, connected with the positive electrode, was dipped into the fused chloride in the tube, being, however, so bent that it could not by any shake of the hand or the apparatus touch the negative electrode at the bottom of the vessel. The whole arrangement is shown in Fig. 162.

Fig. 162.



Under these circumstances the chloride of tin was decomposed; the chlorine evolved at the *positive* electrode formed bichloride of tin, which passed away in fumes, and the *tin* evolved at the negative electrode combined with the platinum, forming an alloy fusible at the temperature to which the tube was subjected, and therefore never occasioning metallic communication through the decomposing chloride. When the experiment had been continued for some time, the battery connections were broken, the positive electrode removed, and the tube and remaining chloride allowed to cool. When cold, the tube was broken, the undecomposed chloride and the glass being easily separable from the platinum wire and its button of alloy. The latter when washed was re-weighed, and the increase gave the weight of the tin reduced.

'The negative electrode weighed at first 20 grains: after the experiment it weighed with the button of alloy 23·2 grains. The tin evolved by the electric current at the cathode weighed therefore 3·2 grains. The quantity of oxygen and hydrogen gases collected in the voltameter amounted to 3·85 cubic inches. Now as 100 cubic inches of oxygen and hydrogen in the proportion to form water may be considered as weighing 12·92 grains, the 3·85 cubic inches collected in the experiment would weigh 0·49742 gr., that being, therefore, the weight of water decomposed by the same electric current that was able to decompose such a weight of protochloride of tin as could yield 3·2 grains of metal.

'Now 0·49742 : 9 (the equivalent of water) :: 3·2 : 57·9 ; 57·9 should, therefore, be the *equivalent* of tin, if the experiment had been without error, and if the electro-chemical decomposition *is in this case also definite.* In some chemical works 58 is given as the chemical equivalent of tin; in others, 57·9. Both are so near to the result of the experiment, and the experiment itself is so subject to slight causes of variation, that the numbers leave little doubt of the applicability of the law of *definite action* in this and all similar cases of decomposition.'

Faraday experimented upon *chloride of lead* in a manner precisely similar, except that *plumbago* was substituted for platinum, as the positive electrode. The mean of three experiments gave 100·85 as the equivalent for lead. The chemical equivalent is 103·5, the deficiency being probably attributable to the solution of part of the gas in the voltameter.

In some experiments several substances were placed in succession, and decomposed simultaneously by the same electric current: thus *protochloride of tin*, *chloride of lead*, and *water* were acted on at once; the results were in harmony with each other, the *tin*, *lead*, *chlorine*, *oxygen*, and *hydrogen* evolved being *definite in quantity*, and electro-chemical equivalents to each other.

(120) **Absolute Quantity of Electric Force in Matter.**—The establishment of the theory of *definite electro-chemical* action led Faraday to the consideration of the absolute quantity of electric force in matter. To decompose a single grain of acidulated water, an electric current powerful enough to retain a platinum wire $\frac{1}{104}$ of an inch in thickness red hot must be sent through it for three minutes and three quarters; and this quantity of electricity *is equal to a very powerful flash of lightning.* Yet the electrical power which holds the elements of a grain of water in combination, or which makes a grain of oxygen and hydrogen in the right proportions unite into water when they are made to combine, equals in all probability the current required for the separation of that grain of water into its elements again, and this Faraday has shown to be equal to 800,000 charges of a Leyden battery of 15 jars, each containing 184 square inches of glass coated on both sides:

indeed, a beautiful experiment is described by Faraday, in which the chemical action of dilute sulphuric acid on 32·21 parts (or one equivalent) of amalgamated zinc, in a simple voltaic circle, was shown to be able to evolve such quantity of electricity in the form of a current, as, passing through water, could decompose 9 parts (one equivalent) of that substance; thus rendering complete the proof (bearing in mind the definite relations of electricity) '*that the electricity which decomposes, and that which is evolved by the decomposition of, a certain quantity of matter, are alike.*'

(121) **Secondary Results.**—When the material out of which the electrodes are formed is liable to the chemical action of the substances evolved, either simply in consequence of their natural relation to them, or of that relation aided by the influence of the current, they then suffer corrosion, and the portions dissolved are subject to transference in the same manner as the particles of the body originally under decomposition. Thus *zinc* can combine with oxygen and acid, and if made the positive electrode it does so combine, and immediately begins to travel as oxide towards the negative pole. *Charcoal*, if made the negative electrode in a metallic solution, refuses to unite to the bodies which are ejected from a solution on its surface; but if made the positive electrode in dilute sulphuric acid, it is capable of combining with the oxygen evolved there, and consequently unites with it, producing both carbonic acid and carbonic oxide.

Again, if the electrodes employed to electrolyse a solution of sulphate of soda be both platinum, the direct results of the voltaic decomposition of the salt are obtained, because the platinum has no tendency to combine with either the hydrogen, oxygen, acid, or alkali evolved; but if platinum be the positive electrode in a solution of *nitrate* or *acetate of lead*, then, instead of oxygen being evolved, *peroxide of lead* is deposited on the plate in consequence of the action of the nascent oxygen on the protoxide of lead. When a compound yields uncombined and unaltered at the electrodes those bodies which have been separated by the electric current, the results are considered as *primary*; but when any second reaction takes place, by which the substances which appear at the electrodes are *not* those which the immediate decomposition of the compounds would produce, then the results are *secondary*, although the bodies evolved may be elementary. Thus, if solution of *ammonia* be decomposed by platinum electrodes, *nitrogen* appears at the positive electrode; but though an elementary body, it is a *secondary* result in this case, being derived from the chemical action of the oxygen evolved there upon the ammonia in the surrounding solution. In the same manner, when aqueous solutions

of certain metallic salts are electrolysed, the metals evolved at the negative pole, though elements, are *secondary* results, and not immediate consequences of the decomposing power of the current.

(122) **Crystallisations and Decompositions by Feeble Currents.**—By exposing different metallic solutions to the action of feeble electrical currents, using electrodes of various nature, some very interesting results were obtained by Becquerel (*Traité de l'Electricité*, tom. iii. p. 287 *et seq.*):—

Suboxide of copper, in the form of small bright octohedrons of a deep red colour, was obtained by filling a tube with a solution of nitrate of copper, placing at the bottom some powdered protoxide, and plunging into the liquid a plate of copper. The tube being then hermetically sealed, the crystals made their appearance in about ten days.

Crystallised protoxide of lead was obtained by placing at the bottom of a tube some pulverised litharge, and pouring over it a slightly diluted solution of subacetate of lead, then plunging in a plate of lead which was equally in contact with the litharge; the tube was then hermetically sealed, and the surface of the plate became gradually covered with crystals of hydrated protoxide of lead.

Crystallised oxide of zinc was obtained thus: two bottles were filled, one with a solution of oxide of zinc in potash, and the other with a solution of nitrate of copper; a communication was established between them by means of a bent tube filled with potter's clay, moistened with a solution of nitrate of potash; a plate of lead was immersed in the solution of zinc, and a plate of copper in the solution of copper. These two plates were put into metallic communication with each other. The nitrate of copper was decomposed in consequence by the current proceeding from the action of the alkali on the lead; the oxygen and the nitric acid were transferred to the lead, and these produced nitrate of potash and oxide of lead, which was dissolved in the alkali.

After the experiment had been continued for some days small clear crystals of oxide of zinc were found deposited on the plate of lead.

Chloride of silver was obtained, in the form of translucent octohedra, by immersing a plate of silver, attached by a wire of the same metal to a piece of charcoal, in a tube containing hydrochloric acid.

Chloride of copper, and the sulphides of *silver*, *lead*, and *tin*, were also obtained in beautifully crystalline forms by a similar method of experimenting.

The attention of Becquerel was subsequently more particularly directed to those weak electrical actions which are set up when rocks and the metallic and other substances which occupy mineral veins and beds, come in contact with the mineral waters which rise from the interior of the earth. The following experiments, among many others, are described:—

1. A plate of amalgamated zinc surrounding a copper wire was plunged into a solution of *silica* in potash. After a fortnight's action, small, regular, octohedral crystals of *hydrated oxide of zinc* were formed on the zinc plate.

2. A *lead-copper* arrangement was substituted for the zinc-copper, crystals of *anhydrous oxide of lead* were deposited on the lead plate.

3. Lumps of *galena* were left for several years in solutions of *chloride of sodium* and *sulphate of copper.* The following products were formed:—(*a*) *chloride of sodium* in cubes and other crystalline forms of great regularity and brilliancy; (*b*) *chloride of lead* in needles and cubes; (*c*) *sulphate of lead* in octohedra; (*d*) *chloro-sulphate of lead* in needles; (*e*) *basic-chloride of lead* in microscopic crystals; (*f*) *sulphide of copper* black, but without any appearance of crystallisation.

Becquerel thinks that similar reactions take place in nature: rain water coming into contact with mineral masses and veins formed of metallic combinations becomes charged with chloride of sodium, and sulphate of copper arising from the decomposition of copper pyrites; the resulting solutions coming into contact with galena, react upon it weakly, and give rise to the various compounds above described.

By operating with weak and long-continued electrical currents, some very interesting results were likewise obtained by Mr. Crosse. Thus, beautiful translucent crystals of carbonate of lime were obtained over the whole surface of a piece of slate immersed in spring water and connected with the *negative* electrode of a sulphate of copper battery, the platinum wire constituting the positive electrode being twisted round a piece of mountain limestone also immersed in the water; in the same way *stalactitic carbonate of strontia* and mammillated *carbonate of baryta*, and the *sulphates* of strontia and baryta in crystalline forms, were obtained by electrifying positively in spring water native carbonates and sulphates of strontia and baryta; the crystals of *silicic acid* were obtained by electrifying positively a piece of solid opaque white *quartz* in a solution of pure carbonate of potash.

By the following simple arrangement, suggested by the late Dr. Golding Bird, fine crystals of *copper*, suboxide of *copper*, and *oxide of zinc* may be obtained:—

A glass tube open at both ends, about half an inch in diameter and three inches in length, is closed at one end by means of a plug of plaster of paris about one-eighth of an inch in thickness. The tube is filled with a moderately dilute solution of nitrate or chloride of copper, and placed inside a cylindrical glass vessel nearly filled with a weak solution of potash or soda. The leaden leg of a compound lead and copper arc is plunged into the outer cylinder and the copper leg into the tube. The lead slowly dissolves in the alkaline solution, and electric action is set up: the current traverses the plaster of paris partition, and the oxide of copper (precipitated by the slow admixture of the alkaline solution with the copper salt) is reduced partly to the metallic state, and partly to suboxide, both of which crystallise on the negative copper leg of the arc. If a solution of oxide of zinc in caustic potash be substituted for the uncombined alkali in the larger vessel, a crystalline deposit of *oxide of zinc* takes place in about eight or ten days on the

lead or positive plate, while fine crystals of *copper* and *suboxide* are deposited on the copper or negative plate.

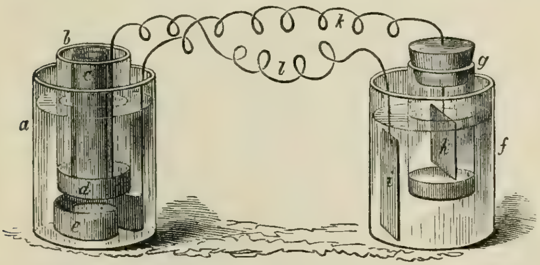
(123) **Electrolytic Reduction of Metals.**—The electro-reduction of the metals of the alkalies was originally accomplished by Davy with a battery of 100 pairs of 6-inch copper and zinc plates, but may be effected with a series of 8 or 10 cells of Grove's or Bunsen's battery in the following manner:—

Let a cavity be scooped in a piece of pure moistened caustic potash or soda, and let it be filled with mercury: lay the alkali on a strip of platinum foil connected with the positive electrode of the battery, and introduce into the mercury a platinum wire in contact with the negative electrode; an amalgam of potassium or sodium with mercury will speedily be formed. In like manner the *ammoniacal* amalgam may be formed by pouring a little mercury into a hole scooped in a lump of sal-ammoniac, and connecting the mercury with the negative and the moistened sal-ammoniac with the positive electrode. This is a very striking experiment, the globule of mercury gradually increasing in size until it extends far beyond the cavity which first contained it. The amalgam is produced more rapidly and copiously if the mercury be previously combined with a small quantity of potassium or sodium.

By means of the little apparatus shown in Fig. 163, the late Dr. Golding Bird succeeded in obtaining amalgams of *potassium*, *sodium*, and *ammonium*, and other metals, in a crystalline form, with the feeble current from a single Daniell's cell (*Phil. Trans.* 1837):—

A glass cylinder *d*, 1·5 inch in diameter and 4 inches in length, is closed at one end by means of a plug of plaster of paris 0·7 inch in thickness; the cylinder is fixed, by means of corks, inside *c*, a cylindrical glass vessel *a*, about eight inches deep and two in diameter. A piece of copper *c*, six

Fig. 163.



inches long and three inches wide, having a copper conducting wire *k* soldered to it, is loosely coiled up and placed in the small cylinder with the plaster bottom; a piece of sheet zinc *e* of equal size is also loosely coiled up and placed in the large external cylinder, being furnished, like the copper plate, with a conducting wire *l*. The larger cylindrical glass being then filled with weak *brine*, and the smaller with a saturated solution of *sulphate*

of copper, the two fluids being prevented from mixing by the plaster of paris diaphragm, the apparatus is complete, and will avail to give a continuous current of electricity for some weeks, provided care be taken that the fluids in the two cylinders are maintained at the same level.

The decomposing cell is the counterpart of the battery itself. It consists of two glass cylinders, one within the other, the smaller one *g* having a bottom of plaster of paris fixed into it; this smaller tube is about half an inch wide and three inches long, and is intended to hold mercury and the metallic solution submitted to experiment; the external vessel *f* in which it is immersed being filled with a weak solution of common salt. In the latter a slip of amalgamated zinc *i* is immersed for the positive electrode, being soldered to the wire coming from the positive plate of the battery; whilst for the negative electrode a slip of platinum foil *h* fixed to the wire from the zinc plate of the battery passes through a cork fixed in the mouth of the smaller tube, and dips into the metallic solution which it contains. In about eight or ten hours the mercury becomes swollen to double its former bulk, and when it is quickly poured into distilled water, hydrogen gas is evolved and the water becomes alkaline. The ammoniacal amalgam was most easily obtained; it had a buttery consistence, and when immersed in water, slowly gave off hydrogen gas, and yielded solution of ammonia.

Bird found that the spongy ammoniacal amalgam, though it cannot be kept immersed in water, even for a few instants, without the formation of ammonia, could, nevertheless, be preserved for weeks without change, as long as it was connected with the negative electrode of the battery.

With the same apparatus, Dr. Bird reduced the metals from solutions of chloride or nitrate of *iron*, *copper*, *tin*, *zinc*, *bismuth*, *antimony*, *lead*, and *silver*. *Bismuth*, *lead*, and *silver* were beautifully crystalline; the latter of dazzling whiteness, and usually in the form of needles. He also obtained *silicon* from a solution of chloride of silicon in alcohol.

The metals *barium*, *strontium*, and *calcium* were obtained by Bunsen by electrolysing their respective chlorides, mixed up to a paste with water and a little hydrochloric acid, at a temperature of 212° Fah., the negative electrode being an amalgamated platinum wire. A crystalline amalgam was thus obtained from which the mercury was distilled off in a stream of hydrogen. *Lithium* was reduced from the fused chloride in a porcelain crucible, the positive electrode being a splinter of gas coke, and the negative an iron wire, the power employed being from four to six cells of the nitric acid battery. *Magnesium* may be obtained from the fused chloride. In a similar manner, *aluminum* may be obtained from a mixture of fused chloride of aluminum and sodium. For the reduction of certain metals, Bunsen places the liquid to be decomposed in a small porous cell standing in a carbon crucible, which constitutes the positive electrode, the negative being a narrow strip of platinum dipping into the liquid. The whole is heated over a water-bath. The metals *chromium* and *manganese* may be obtained in a state of perfect purity by electrolysing in the above manner concentrated solutions of their chlorides.

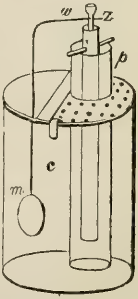
(124) **Electro-metallurgy.**—When the circuit is completed in a cell of the sulphate of copper battery of Daniell, the electrical current passes freely through the metallic solution; no hydrogen makes its appearance on the conducting plate, but a coating of pure copper is deposited upon it. In the discovery of this battery, then, we find the origin of the now extensive art of electro-metallurgy; for it appears that in his earlier experiments it was noticed by Mr. Daniell that on removing a piece of the reduced copper from a platinum electrode, scratches on the latter were copied with accuracy on the copper; and Mr. de la Rue made the observation (*Phil. Mag.*, vol. ix. p. 484), that 'the copper plate is covered with a coating of metallic copper which is continually being deposited, and so perfect is the sheet of copper thus formed, that on being stripped off, it has the polish, and even the counterpart, of every scratch of the plate on which it is deposited.'

The first practical applications of this fact were made by Jacobi, of St. Petersburgh (Feb. 1837), and by Spencer and Jordan (1838), of Liverpool.

The first kind of apparatus employed by Spencer was simply a common tumbler to hold the copper solution, and a gas glass, having one end closed with brown paper or plaster of paris, to contain the saline solution; the coin to be copied, and a piece of zinc the same size, were attached to the extremities of a piece of copper wire. The gas glass being fixed in the axis of the tumbler, the zinc was placed in it, and the copper wire bent in such a manner as to bring the coin immediately under it in the copper solution. The battery process was subsequently described by Mr. Spencer, and the method of giving a conducting surface to non-metallic substances, by rubbing them over with plumbago, was suggested by Jacobi, but introduced into this country by Mr. Murray.

The single-cell apparatus is shown in Fig. 164.

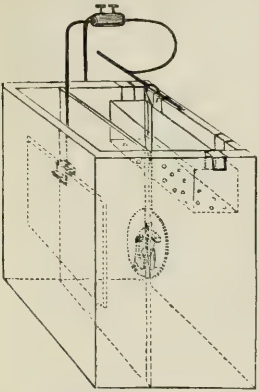
Fig. 164.



z is a rod of amalgamated zinc; *m* the mould; *w* the wire joining them; *c* the copper solution; *p* a tube of porous earthenware, containing a solution of the acid and water. To put it in action, the copper solution (which must be kept saturated by keeping the perforated shelf well supplied with crystals of sulphate of copper) is poured in, the porous tube is then filled with acid water and placed as in the figure, and then the mould is plunged into the copper solution and attached to the zinc rod. The mould must not be too small in proportion to the size of the zinc, and the concentrated part of the solution must not be allowed to remain at the bottom or the copy will be irregular in thickness.

Another form of the single-cell arrangement, in which neither acid nor mercury is used, is shown in Fig. 165.

Fig. 165.

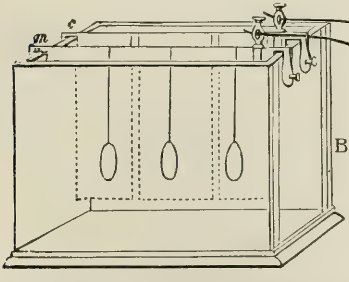


It consists of a wooden box well varnished in the interior, and divided into two unequal cells by a partition of porous wood. The larger cell is filled with a saturated solution of sulphate of copper, the smaller with a half-saturated solution of sal ammoniac. In the former is a shelf containing a supply of crystals. The zinc plates are *pure.* The action is not equally quick with that resulting from the addition of acid, but it will be *sure*, and, as Mr. Walker observes, failure more frequently results from the power of the battery being too strong than from its being too weak.

The battery apparatus is shown in Figs. 166 and 167.

A (Fig. 166) is a cell of the sulphate of copper battery; B is the decomposition cell filled with an acid solution of sulphate of copper; *c* a sheet of copper connected with the positive pole of the battery to keep the solution supplied with copper salt; *m* a strip of metal connected with the negative pole, from which the moulds intended to receive the copper deposit are suspended by metal wires. To charge the arrangement, the solutions are poured in, the wire *z* is connected with the copper sheet, and, *lastly*, the wire *x* with the moulds. The charging liquid is a mixture of *one* part sulphuric acid, *two* parts of the saturated solution of sulphate of copper, and *eight* parts of water.

Fig. 166.

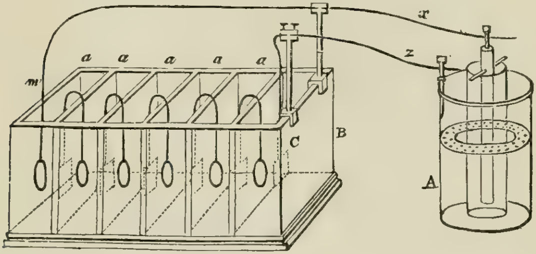


When the circuit is completed, the copper from the solution is transferred to the moulds, and the copper sheet undergoes oxidation and solution, thus keeping up the strength of the liquid. Rather a longer time is required by this method than with a single cell, but two days will produce a medal of

very good substance, firm and *pliable*. The time required depends, however, much on the *temperature*.

In the arrangement shown in Fig. 167, six *electrotypes* may be taken off at the same time: A is the battery; B the trough; *z* the wire connecting the copper plate *c* with the copper cell of the battery; *x* the wire connecting the moulds with the zinc of the battery; *a a a a a* five bent copper wires, each having a mould at one end and a piece of copper at the other.

Fig. 167.



The following directions for charging this trough are given by Mr. Walker (*Electrotype Manipulation*):—'Connect the copper plate *c* with the battery; place a wire with its extreme ends dipping in the extreme ends of the trough; then, having previously connected the zinc and mould with the wire *x*, place the zinc in the porous cell and the mould in the place at *m*; in about two minutes it will be covered with copper. After this there is no fear of chemical action. Then remove the end of the copper wire from the cell containing *m*, and place it in the next cell, complete the circuit with the bent wire *a*, having a mould at one end and a piece of copper at the other. After waiting two minutes for a deposit of copper, remove the end of the wire one cell further forward; and so continue till the six moulds are placed in.'

The advantage in point of economy from using this last form of decomposition trough is apparent, when it is considered that for every *ounce* of copper released from the solution in the generating cell, one *ounce* will be deposited on *each* mould, and about an *ounce* of zinc will be consumed in effecting this. Whether, therefore, one, six, or even twenty moulds be placed in series, the same quantity of zinc will be required; and hence one ounce of zinc may be made to furnish electricity enough to produce, according to the will of the experimenter, one or six or more medals, each weighing one ounce. If the solution be concentrated, the more slowly the action takes place, the harder and more crystalline the deposit. By modifying the power of the battery and the strength of the solution, the deposited copper may be obtained of any desired degree of toughness.

In Elkington's large depositing works at Birmingham the old form of Wollaston battery is principally employed; it is worked as a single pair. A new battery will work well for four days, and the acid (one sulphuric acid and eight water) lasts about one month. It is reckoned that 2 lbs. of zinc are consumed for every pound of copper deposited. The objects on which the copper is deposited should have the same surface area as the zinc of the battery. No crystals of sulphate of copper are suspended in the depositing troughs, which are six feet deep, and hold about 1,600 gallons; the liquor lasts five years without changing or adding either acid or sulphate of copper. Particular attention is paid to the temperature both of the battery room and the depositing room; it is kept as nearly as possible at 60° Fah.

To take impressions from medals or other works of art it may be required to copy, Gore recommends (*Pharm. Jour.*, July 1855) a mixture of two parts gutta-percha and one part of marine glue; the materials are to be cut up and the glue melted at a gentle heat and incorporated with the gutta-percha. The paste is to be applied whilst soft, with a pressure gradually increasing, to the surface of the object to be copied. Moulds of plaster of Paris must be immersed in melted wax or tallow to render them impervious to moisture, and afterwards well covered with the best black lead. In all cases the backs of the moulds, if the material is a conductor of electricity, must be coated with a resinous varnish to prevent a metallic deposit from taking place at those parts.

One elegant method of producing a conducting surface upon flowers, leaves, fruits, and other delicate articles, was invented by Captain Ibbetson. It consists in immersing them in a weak solution of *phosphorus* either in ether or in bisulphide of carbon, allowing the solvent to evaporate from the surface, and then plunging the objects into a solution of nitrate of silver; in this way a film of metallic silver is deposited, upon which the deposit from the battery may be received. If a steel plate is to be copied, it must be electrotyped in silver previous to introducing it into the copper solution. In the process of *electrozincing*, which is carried on very extensively, the iron plates, rods, or chains are immersed in a solution of sulphate of zinc, and connected with the negative electrode of the battery, a plate of zinc forming the positive electrode; the power required is very small.

(125) **Electro-plating.**—Silver cannot be obtained in the form of coherent plates by electrolysing a solution of its nitrate, the metal being deposited in a granular or crystalline form however slow the action. The same is the case with gold and platinum when the chlorides of these metals are electrolysed. In the pro-

cesses of electro-silvering and electro-gilding, the double cyanides of silver or of gold with potassium or calcium are employed, the positive electrodes being silver and gold.

The preparation of the argento- and auro-cyanide solutions in Elkington's large electro-metallurgical establishment is as follows (*Napier*):—

The best yellow prussiate of potash is well dried upon an iron plate, and then reduced to a fine powder; carbonate of potash is similarly treated: eight parts of the former are well mixed with three of the latter. They are then placed in a hot iron pot on the fire, and when melted are covered and allowed to remain for about half an hour; the contents are then poured upon an iron plate, and form the simple *cyanide of potassium.* Nitrate of silver is next prepared and precipitated in the form of cyanide of silver by the careful addition of cyanide of potassium; it is well washed, and is now dissolved in excess of cyanide of potassium to form *argento-cyanide.* A solution which contains one-fiftieth of its weight of silver is found to be a convenient strength.

The articles to be plated are first boiled in potash, then scoured with fine sand, afterwards passed through nitric acid, and then washed in boiling water. After a few seconds of electric action, they are brushed with a scratch-brush to perfect the cleaning, and are then placed in the solution to complete the plating, which process is accomplished in five or six hours. After this they are burnished.

Four cells of Wollaston's battery, the zinc plates being 32 inches long and 16 inches wide, deposit 24 oz. of silver per hour. If a few grains of bisulphide of carbon dissolved in ether are added to the silver bath the metal is deposited bright, without the bisulphide it is thrown down *dead*, but a careful management of the battery is required; if the power be too great the effect is not produced, and the deposited metal is apt to blister.

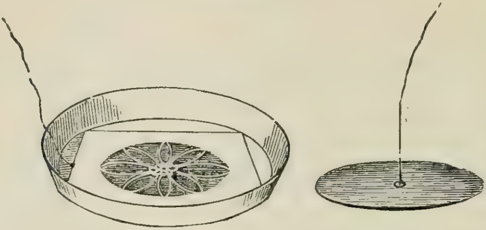
The magneto-electrical machine is largely employed at Messrs. Elkington's works instead of the voltaic battery for electro-plating. From the apparatus at present employed, 17 oz. of silver are deposited per hour.

The *auro-cyanide* is not so easily prepared as the *argento-cyanide.* The plan formerly adopted was to dissolve oxide of gold in cyanide of potassium. The solution is now generally prepared by electrolysis. A porous tube containing cyanide of potassium in solution is placed within a vessel of a similar solution; within the tube is a *gold positive* electrode, within the vessel the *negative* electrode is placed. The liquid is electrolysed, and the gold being dissolved forms the gilding solution, which is removed from the porous tube for use when sufficiently saturated; the liquid in the outer vessel becomes a solution of *potash.* Electro-gilding is conducted with a solution at the temperature of 212° Fah.

(126) **Mettallo-chromes.**—When acetate of lead is electrolysed under peculiar circumstances, it gives rise to secondary results of a very beautiful character: *peroxide of lead* is deposited at the positive electrode, and by carefully regulating the thickness of this compound a series of most magnificent colours may be produced on a plate of highly polished steel. The process recommended by Mr. Gassiot to form these *metallo-chromes* is this:—

Place the polished steel plate in a glass basin containing a clear solution of acetate of lead, and over it a piece of card with some regular device cut out, as shown in Fig. 168. A small rim of wood should be placed over the

Fig. 168.



card, and on that a circular copper disc. On contact being made from 5′ to 20′, with two or three cells of a small constant battery, the steel plate being connected with the *positive* electrode, and the copper disc with the negative, the deposit will be effected, and a series of exquisite colours will appear on the steel plate. These colours are films of *peroxide of lead* thrown down on the surface of the steel, and the varied tints are occasioned by the varying thicknesses of the precipitated film, the light being reflected through them from the polished metallic surface below. By reflected light every prismatic colour is seen; and by transmitted light a series of prismatic colours complementary to the first series appears, occupying the place of the former series.

The colours are seen in the greatest perfection by placing the plate before a window, and inclining a white sheet of paper at an angle of 45° over it.

(127) **Electrolysis of Salts.**—From an elaborate series of experiments by the late Professor Daniell on the sulphates of potash, soda and ammonia, nitrate of potash, &c., it appears—

'That in the electrolysis of a solution of a neutral salt in water, a current which is just sufficient to separate *single equivalents* of oxygen and hydrogen from a mixture of sulphuric acid and water, will separate single equivalents of oxygen and hydrogen from the saline solution, while single equivalents of acid and alkali will make their appearance at the same time at the respective electrodes.'

And further experiments showed, that when dilute sulphuric acid was used, there was a transfer of acid towards the *zincode* (anode), the quantity scarcely ever exceeding the proportion of one-fourth of an equivalent as compared with the hydrogen evolved. Mr. Daniell thought this might possibly be owing to the acid being mechanically carried back to the *platinode* (cathode), as in all cases there is a mechanical convection of the liquid from the positive to the negative pole (128), and this is greater in proportion to the inferiority of its conducting power. If, however, this deficiency of acid were owing to the mechanical *re-transfer*,

mechanical means, such as increasing the number of diaphragms, would stop it; the proportion, however, was, even under these circumstances, still maintained. No difference was observed, whether the oxygen was allowed to escape from a platinum anode, or whether it was absorbed by copper or zinc, the metals, of course, being dissolved in proportions equivalent to the hydrogen developed at the cathode; solutions of potash, baryta, and strontia, similarly treated, exhibited a transfer of about *one-fourth* of an equivalent towards the cathode. When fused chloride of lead was included in the circuit in the place of the voltameter, the cathode being a platinum wire and the anode a piece of plumbago, results were obtained which showed that—

'The same current which is just sufficient to resolve an equivalent of *chloride of lead* (which is a *simple* electrolyte unaffected by any associated composition) into its equivalent *iöns* produces the apparent phenomenon of a resolution of water into its elements, and at the same time of an equivalent of sulphate of soda into its proximate principles.'

Electrolysis of Chlorides.—A weighed plate of pure tin was made the anode in a double cell of peculiar construction, which was charged with a strong solution of chloride of sodium, and a tube of fused chloride of lead was included in the circuit. Not a bubble of gas appeared on the tin electrode, and no smell of chlorine was perceptible; but the hydrogen in equivalent proportion to the quantity of tin dissolved was given off at the cathode, and the cell contained an equivalent proportion of free soda; one equivalent of lead was reduced in the voltameter tube. Chloride of ammonium treated in the same way gave precisely similar results, proving it to be an electrolyte whose *simple* anion was chlorine, and whose *compound* cathion was nitrogen with four equivalents of hydrogen (NH_4, *ammonium*).

Electrolysis of Sulphate of Copper.—The following experiment was made by Professor Daniell:—

A small bell glass, with an aperture at the top, had its mouth closed by tying a piece of membrane over it. It was half filled with a dilute solution of caustic potash, and suspended in a glass vessel containing a strong solution of neutral sulphate of copper, below the surface of which it is just dipped. A platinum electrode connected with the last zinc rod of a large constant battery (Fig. 137, p. 183) of twenty cells was placed in the solution of potash; and another connected with the copper of the first cell was placed in the sulphate of copper immediately under the diaphragm which separated the two solutions. The circuit conducted very readily, and the action was very energetic. Hydrogen was given off at the *cathode*, and oxygen at the *anode*, in the sulphate of copper; a small quantity of gas was also seen to rise from the surface of the diaphragm. In about ten minutes the lower surface of the membrane was found beautifully coated with metallic copper, interspersed with black oxide of copper and light blue hydrated oxide.

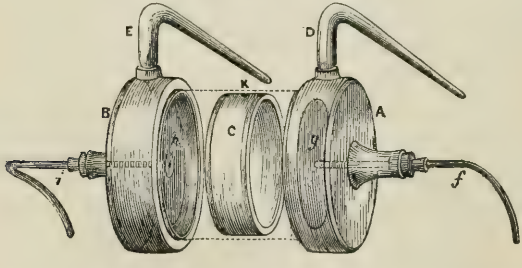
The explanation of these phenomena is this :—

In the experimental cell we have two electrolytes, separated by a membrane, through both of which the current must pass to complete the circuit. The sulphate of copper ($CuSO_4$) is resolved into its compound *anion* (SO_4), and its simple *cathion* (Cu) ; the latter in its passage to the cathode is stopped at the surface of the second electrolyte, which may be regarded as water improved in conducting power by potash. The metal here finds nothing by combining with which it can complete its course, but, being forced to stop, yields up its charge to the hydrogen of the second electrolyte, which passes on to the *cathode*, and is evolved. The corresponding oxygen stops also at the diaphragm, giving up its charge to the *anion* of the sulphate of copper. The copper and oxygen, thus meeting at the intermediate point, partly enter into combination, and form the black oxide ; but from the rapidity of the action, there is not time for the whole to combine, and a portion of the copper remains in the metallic state, and a portion of the gaseous oxygen escapes. The precipitation of blue hydrated oxide doubtless arose from a mixing of a small portion of the two solutions.

Nitrate of silver, *nitrate of lead*, *protosulphate of iron*, *sulphate of palladium*, and *protonitrate of mercury* were similarly treated, and afforded analogous results, somewhat modified by the nature of the metallic base.

Electrolysis of Bisalts.—A strong solution of pure crystallised bisulphate of potash was made, and its neutralising power carefully ascertained by the alkalimeter. Evaporation and ignition with carbonate of ammonia gave the quantity of neutral sulphate yielded by a certain measure of the solution. An equal measure was then placed in each arm of the double diaphragm cell (Fig. 169), an apparatus which Daniell found very useful in his experiments on the electrolysis of secondary compounds.

Fig. 169.



A and B are two halves of a stout glass cylinder, accurately ground so as to fit into two half-cylinders, which, when adjusted, cover it entirely. The two rims of the ring are each cut down to the shoulder, to admit of a thin piece of bladder being tied over them to form a kind of drum. At K is a small hole to admit of the cavity being filled with a liquid. D and E are two

stout bent tubes fitted to the two half-cylinders, for collecting the gases evolved in the experiments; *g* and *h* are two circular platinum electrodes, connected with the battery by the wires *i* and *f*. The apparatus, when adjusted, forms three compartments, each of which may be filled with the same or a different liquid, and the whole supported on a wooden frame.

The voltaic current was passed through till 70·8 cubic inches (or the quantity yielded by 9 grains of water) of mixed gases were collected; half the solutions from the *anode* and *cathode* were then separately neutralised, and half evaporated and ignited in the vapour of carbonate of ammonia. It was then found that the *anode* had gained 18 grains, and the *cathode* had lost 19 grains of *acid*; of potash, the *anode* had lost 9·9 grains, and the *cathode* had gained an equal quantity. Thus, though the solution conducted very well, not more than *one-fifth* of an equivalent of potash was transferred to the cathode, as compared with the hydrogen evolved; while *half* an equivalent of acid was transferred to the *anode*, a *whole* equivalent of oxygen was evolved. On this experiment Mr. Daniell remarks:—

'I think we cannot hesitate to admit that in this case the current divided itself between two electrolytes: that a part was conducted by neutral sulphate of potash, and a larger part by the sulphuric acid and water. It is a well-known fact that the voltaic current will divide itself between two or more *metallic* conductors in inverse proportion to the resistance which each may offer to its course; and that it does not in such cases choose *alone* the part of *least* resistance. Analogy would lead one to expect a similar division of a current between two electrolytes; but I am not aware whether such a division has ever before been pointed out.'

These considerations enable us to explain the apparent anomalies in the electrolysis of dilute sulphuric acid and alkaline solutions. The results are explained by supposing that the solution is a mixture of two electrolytes. With sulphuric acid the component *iöns* are H and SO_4 (*sulphionide of hydrogen*); with water they are H and O. The current so divides itself that three equivalents of water are decomposed, and one equivalent of sulphionide of hydrogen. Analogous changes occur with the alkaline solutions, the alkaline metal passing as usual to the cathode.

In the electrolytic decomposition of saline solutions, the oxygen and hydrogen gases evolved are *secondary* products. In Faraday's experiment with sulphate of magnesia (116), for example, the electrolyte was *sulphionide of magnesium* ($MgSO_4$), the simple *cathion magnesium* (Mg) being liberated at the *cathode*, and the compound anion *sulphion* (SO_4) at the *anode*; but sulphion does not exist in a separate form; it therefore takes hydrogen from water, and forms *sulphionide of hydrogen*, oxygen gas being evolved at the *anode*. The magnesium, in like manner, decomposes water,

taking oxygen, with which it forms *magnesia*, which is precipitated, and hydrogen gas escapes at the cathode.

When *monobasic* salts are electrolysed, the acid and base are liberated in single equivalents; but when *polybasic* salts are submitted to analysis, for each atom of fused chloride of lead which is electrolysed in the voltameter, two atoms of base appear at the cathode; but when *basic* salts are decomposed, two atoms of monobasic acid are liberated at the anode for every atom of chloride of lead reduced in the voltameter, whilst all the atoms of base which were previously in combination with the acid are liberated at the cathode.

When tribasic acetate of lead was electrolysed, the electrodes being plates of lead, Miller (*Elements of Chemistry*, vol. i. p. 486) obtained two atoms of oxide of lead, and somewhat less than one atom of metallic lead, at the cathode, for every two atoms of acetic acid which appeared at the anode, and the explanation he gives is this:—

'The oxide of lead is attached to the normal acetate in a manner analogous to water of crystallisation, and the normal acetate is the true electrolyte, whilst the oxide is left upon the electrode in an insoluble form as soon as the acid which kept it in solution is removed.'

(128) **Electrical Endosmose.**—*Motion of Fluids from the Positive to the Negative Electrode.*—This phenomenon, which was first observed by Porrett, has been confirmed by Miller, Wiedemann, Quincke, and Crosse. The apparatus employed by Wiedemann (*Silliman's Journal*, Nov. 1852) consisted of a porous earthenware cell, closed at the bottom, and terminated above by a glass bell, firmly cemented to the upper edge of the cylinder. Into the tubulure of the bell a vertical glass tube was fitted, from which a horizontal tube proceeded so as to permit the fluid raised to flow over into an appropriately placed vessel; a wire, serving as the negative electrode of the battery, passed down through the glass bell into the interior of the porous cylinder, where it terminated in a plate of platinum. Outside the porous cylinder another plate of platinum was placed, and connected with the positive electrode. The whole stood in a large glass vessel, which, as well as the interior porous cylinder, was filled with water. The intensity of the current was measured by the galvanometer. As soon as the circuit was closed, the liquid rose in the porous cylinder, and flowed out from the horizontal tube into a weighed vessel. Wiedemann's results, which have been confirmed by Quincke, were—

1. The quantity of fluid which flows out in equal times is directly proportional to the strength of the current.

2. Under otherwise equal conditions, the quantities of fluid flowing out are independent of the magnitude of the conducting porous surface.

3. The height to which a galvanic current causes a fluid to rise is directly proportional to the extent of the porous surface.

4. The force with which an electric tension present upon both sides of a section of any given fluid urges the fluid from the positive to the negative side is equivalent to a hydrostatic pressure which is directly proportional to that tension.

The greater the resistance which the liquid offers to electrolysis the greater is the amount which is thus mechanically carried over; thus Crosse found that, when the pipe-clay which he employed in his experiments was mixed with dilute sulphuric acid instead of distilled water, no water was raised upwards towards the negative electrode.

CHAPTER XI.

VOLTAIC ELECTRICITY (*continued*).

THERMAL AND LUMINOUS EFFECTS OF THE VOLTAIC PILE.

Heat and Light of the Voltaic Disruptive Discharge—Electric Lamps—The Voltaic Arc—The Intensity of its Light and Heat—Luminous Discharge of Voltaic Batteries in Carbonic Acid Vacua—Investigations of Gassiot.

(129) **Thermal Effects.**—When a voltaic current passes along a metallic conductor, heat is developed; and if the current is greater than the metal is able to convey, it is fused and even dissipated in vapour. The heating power of an extensive voltaic battery is enormous; the most refractory substances succumb to it; platinum, iridium, and titanium, which withstand the heat of the most powerful furnace, are readily fused.

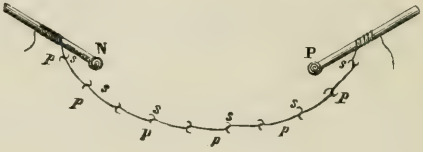
The colour of the light which attends the voltaic disruptive discharge varies with the substances between which the discharge passes. If thin metallic leaves be employed, they are deflagrated with considerable brilliancy. The beautiful effects are not, however, caused by the combustion of the metals, though in many cases increased by this cause, but arise from a dispersion of their particles analogous to that of the more momentary explosion of the Leyden battery. *Gold* emits a white light tinged with blue; *silver* a beautiful emerald green light; *copper* a bluish white light, with red sparks; *lead* a purple; *zinc* a brilliant white light, tinged with red. The experiments may be performed by fixing a plate of polished tinned iron to one wire of the battery, and taking up a

leaf of the metal on the point of the other wire, and bringing it in contact with the tin plate. Even under distilled water, the disruptive discharge of the voltaic battery takes place in a stream of brilliant light.

To show the power of the voltaic current to heat metallic wire, about eighteen inches of the wire may be rolled into a spiral and placed in the interior of a glass tube (Fig. 170), its ends being attached to screws so as to be readily connected with the terminal wires of the battery; by this means a high temperature may be communicated to the glass tube, though the wire may not be ignited, and by immersing it in a small quantity of water, that fluid may be speedily raised to the boiling point. When a wire is heated by the voltaic current, the temperature frequently rises first or most at one end; but it was shown by Faraday that this depends on adventitious circumstances, and is not due to any relation of positive or negative as respects the current.

Fig. 170.

Fig. 171.



The thermal effect of a voltaic current on a metallic wire depends on its conductibility; thus the current which will fuse a wire of iron or platinum may not even render incandescent a wire of the same length of copper or silver. This is illustrated by disposing a chain formed of alternate links of silver and platinum between the poles of a battery (Fig. 171); the platinum links will become red hot during the passage of the current, while the alternate silver links will remain dark. The discharge which passes freely along the silver meets with sufficient resistance in the platinum to produce ignition. The conducting power of a metal is considerably diminished by heating it; thus a wire that is heated to redness through its entire length by a voltaic current may be

fused by dipping a portion of it in cold water, the effect of cooling being to increase the conducting power of the wire, which is in fact equivalent to shortening the length through which the current passes. The *size* of the wire heated by a battery depends on the extent of the surface of the electromotive elements, the *length* on the number of the series, the quantity of electricity remaining the same. Faraday found that the same quantity of water was decomposed by a battery whether half an inch or eight inches of red-hot wire were included in the circuit, and he observes that a fine wire may even be used as a rough but ready regulator of a voltaic current; for, if it be made part of the circuit, and the larger wires communicating with it be shifted nearer to, or further apart, so as to keep the portion of the wire in the circuit sensibly at the same temperature, the current passing through it will be nearly uniform.

There is a striking difference between the heat generated in a platinum wire by a voltaic current according as the wire is immersed in atmospheric air or in other gases. Mr. Grove caused the same current to pass through two platinum wires of the same length, one being enclosed in a tube filled with oxygen, and the other in a similar tube filled with hydrogen, and each immersed in a separate vessel containing three ounces of water; the wire in the oxygen tube became white hot, and in five minutes the temperature of the water rose from 60° to 81°; the wire in the hydrogen tube was not visibly ignited, and in five minutes the temperature of the water rose from 60° to 70° only. Similar experiments were made with other gases, but none came near to hydrogen in its cooling effect on the wire. The amount of gas obtained in a voltameter included in the circuit was in some inverse ratio to the heat developed in the wire; thus, when the wire was surrounded with hydrogen, 7·7 cubic inches of gases were collected, but when it was surrounded with oxygen, 6·5 cubic inches only, and when surrounded with nitrogen, 6·4 cubic inches. This remarkable property of hydrogen arises from its fluency, in consequence of which it exerts a cooling effect on the wire, thereby increasing its conducting power, and so causing it to evolve less heat during the transmission of the current than a similar wire surrounded by a gas such as oxygen, which has not the same degree of fluency.

While operating with a powerful battery of 160 cells, Mr. Gassiot made the observation that the wire connected with the positive pole becomes much hotter than that connected with the negative. When the two wires were crossed, and their ends placed in two similar jars containing distilled water, in about two minutes the water in the positive cell boiled, that in the other

presenting no such appearance. With this battery large bars of platinum were readily fused, and rhodium, iridium, and titanium melted in considerable quantities.

(130) **Luminous Effects.**—When two pencils of well-burnt box-wood charcoal, or, still better, that dense plumbago-like substance found lining the interior of long-used coal retorts, are attached to the terminal wires of a powerful voltaic battery, brought into contact, and then separated, a spark or flame of surpassing brilliancy is produced of an arched form, arising from the ascensional force of the heated air. This arc cannot be obtained between the charcoal points until after they have been brought into contact, and are heated round the points of contact. Mr. Gassiot failed in obtaining the slightest spark before contact with a battery of 320 cells. A single fold of a silk handkerchief, or even a piece of dry tissue paper, was sufficient to insulate the power of the battery, though, after the circuit had once been completed, it fused titanium, and heated to redness sixteen feet four inches of No. 20 platinum wire.

The dazzling light of the voltaic arc arises from the transfer of intensely heated particles of carbon from the positive to the negative electrode, and it is especially sensible *in vacuo*. A cavity is observed to be formed in the point of the positive charcoal, presenting the appearance of a hollow cone, into which the solid cone on the negative terminal might penetrate almost exactly. This is especially observed when the disruptive discharge takes place *in vacuo*, no oxygen being then present to burn portions of the carbon during the transfer.

It is this more rapid consumption of the positive than the negative carbon which has hitherto been one of the chief difficulties in the application of the electric light to practical illuminations. Numerous self-acting regulators for the maintenance of a constant current through the carbon electrodes have been invented. That of L. J. Duboscq, which was exhibited at the International Exhibition of 1862, is found to answer excellently for experiments, or for the lecture room; but it is not suited to lighthouses, or for public lamps, because, if extinguished by any accident, it is not spontaneously relighted.

The two carbon electrodes are fixed one over the other on frames connected by racks and gearing, so that, when the upper electrode descends, the lower one rises. The wheel work is so arranged that the relative motion of these two electrodes shall be such as to compensate for the unequal consumption of the positive and negative carbon electrodes.

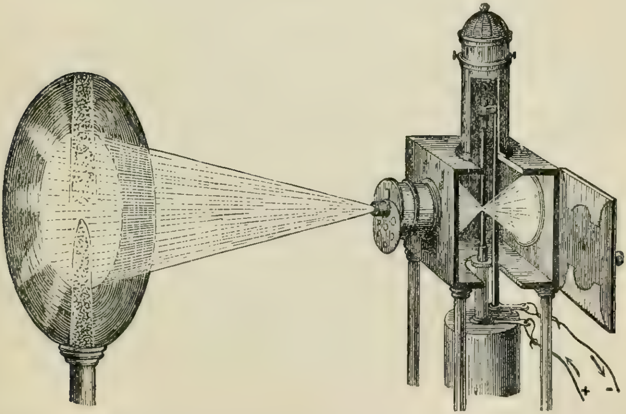
The light is maintained in a constant position by this arrangement, which would not be the case if only one electrode were movable and the other fixed, or if the two moved through equal distances; a barrel spring is em-

ployed to drive the clockwork which moves the electrodes. The clockwork is stopped by a detent, which gears with an escapement wheel. The detent is connected with the armature of an electro-magnet, and allows one or more teeth of the escapement wheel to pass whenever the current is below a certain strength. Thus step by step the carbon points are allowed to approach.

In order to light this lamp, one of the carbon electrodes must be brought in contact with the other by hand, and then removed to a certain distance; this can be done without interfering with the train of wheels. The distance from each other at which the electrodes remain, or rather the strength of current at which the escapement wheel is freed, can be regulated by altering the distance between the electro-magnet and its armature, and thus altering the attraction between them for a given current.

(131) **Electric Lamps.** *Duboscq's Lamp.*—A modification of this lamp is represented in Fig 172, arranged to throw the image of the carbon terminals, during ignition, by means of a lens, on a screen. It shows in a beautiful manner the gradual wearing away of the positive and the increase of the negative electrode. The small globules or specks observed on the charcoal arise from the fusion of the minute quantities of silica contained in the coal.

Fig. 172.



When the voltaic circuit is established, the *negative* carbon first becomes luminous, but the light from the positive is afterwards much the more intense; and as this is the terminal which wears away, it should be somewhat thicker than the other.

Holmes's Lamp.—The construction of this lamp, which the inventor uses in connection with his magneto-electric machine, is very simple, but it produces a very regular and constant light, en-

tirely free from flashes. It is thus described in the *Jurors' Report of Electrical Instruments* (International Exhibition, 1862):—

'Two cords are wound in opposite directions round two portions of one shaft of unequal diameters. The cord from the larger portion of the axis is led down under a pulley on the frame, which carries the upper electrode, and then up to a lever, the functions of which will be described presently. The bight of the cord under the pulley supports the upper electrode with its frame. Similarly the cord from the smaller part of the axis is led down under a pulley on the frame carrying the lower electrode, and then up to a pin which can be turned round by hand, so as slightly to lengthen or shorten the cord. The bight of the second cord supports the lower frame and electrode. The upper frame would, if unchecked, fall down, unrolling its cord from the larger portion of the shaft, and consequently raising the lower frame and electrode. The rise of one and the fall of the other take place in the proportion of the diameter of the two parts of the axis. This movement is checked by a detent gearing into a star escapement wheel. The armature of an electro-magnet frees this wheel when the current falls below a given strength, depending on the adjustment of an antagonistic spring attached to the armature; a continuous feed is thus produced exactly similar to that obtained from Duboscq's lamp. The pin already mentioned, by shortening or lengthening the cord of the lower electrode, allows its height to be adjusted with ease and accuracy, so as to bring the light into the exact centre of a reflector or lens if necessary.

'The lever to which the one end of the cord of the upper electrode is secured is so centred that by slight rocking it lifts or lowers the one end of the cord, and consequently the whole frame or electrode. This motion is confined within small limits by stops. A weight on the other end of the rocking lever nearly balances the weight of the upper frame; and an armature attached to this weight hangs immediately over a second electro-magnet. When no current circulates through the lamp, the weight of the frame and electrodes overbalances the counterpoise, the armature is lifted from the second electro-magnet, and the end of the lever carrying the cord falls, lowering the upper electrode; but, when the current is passing, the armature of this electro-magnet is attracted, and, with the aid of the counterpoise, pulls down one end of the rocking lever, lifting the cord and consequently the upper electrode. The first electro-magnet then works the detent regulating the continuous feed. If the current fail for an instant—if, for instance, the light be blown out—the armature of the second magnet flies up, the upper electrode falls into contact with the lower, re-establishes the current, and again is drawn up to the original distance, so that the lamp is re-lighted.'

Other forms of electric lamp have been contrived by Jaspar, Gressler, Murray and Heath, and others, for descriptions of which we must refer to the *Jurors' Report* above alluded to. The cost, however, of the electric power, the intensity of the light, and the difficulty of producing uniform illumination, have until lately been insurmountable barriers to the application of the electric light to the purpose of general illumination.

By using 600 cells of Bunsen's carbon battery, Despretz obtained a voltaic arc 7·8 inches in length.

(132) **Intensity of the Light of the Voltaic Arc.**—This has been examined by Casselmann (*Pogg. Ann.*, lxiii. 576). The intensity of the light was measured by a Bunsen's photometer, and the strength of the current by a tangent galvanometer, and expressed by chemical units.

	Distance between charcoal points	Strength of current	Intensity of light
	Millimetres		
Crude charcoal . . .	0·5	95	932
	4·5	68	139
Charcoal saturated with nitrate of potassium .	0·5	120	353
	6·75	88	274
Charcoal saturated with caustic potash . . .	2·5	101	150
	8·0	82	75
Charcoal saturated with chloride of zinc . . .	1·0	80	624
	5·0	67	159
Charcoal saturated with borax and sulphuric acid	1·5	72	1171
	5·0	64	165

The advantage gained by saturating the carbon terminals with saline solutions consisted in obtaining a more voluminous and a steadier light than could be obtained from the crude charcoal, tinged however with colours corresponding to the solutions employed. The numbers in the table demonstrate a diminution, both in the strength of the current and in the intensity of the light, in proportion as the distance between the terminals is increased. According to the experiments of Fizeau and Foucault, the intensity of the voltaic arc produced by 46 pairs of Bunsen's nitric acid battery is 34 times as great as that of the oxy-hydrogen light. They obtained from 80 elements in series, very little greater intensity than from 46 elements; but, when the plates were so arranged as to form fewer elements of larger size, a great increase in the intensity was obtained. According to Bunsen, the intensity of the light between carbon electrodes a quarter of an inch apart, from 48 couples of his battery, is equal to that of 572 candles.

(133) **Influence of Magnetism on the Voltaic Arc.**—It was first observed by Davy that a powerful magnet acts on the voltaic arc as upon a movable conductor traversed by the electric current. It attracts and repels it, and this attraction and repulsion manifests itself by a change in the form of the arc, which may even become broken by too great an attraction or repulsion. Fig. 173 represents the voltaic flame between two cylinders of

plumbago, and Fig. 174 the curved form which it assumes under the influence of a magnetic pole.

Fig. 173.

Fig. 174.

De la Rive found that the arc could only be formed between two magnetised iron electrodes when they were brought very close, and then in the form of noisy sparks, as if the transported particles of iron disengaged themselves with difficulty from the positive electrode. When a platinum plate was placed upon one of the poles of a powerful electro-magnet, and made the negative electrode, a point of platinum placed vertically above it being made the positive electrode, a sharp hissing sound was heard; this was not the case when the electrodes were reversed, but then the luminous arc no longer maintained a vertical direction, but was projected outwards towards the edge of the plate; it was incessantly broken, and sounds similar to the discharge of a Leyden jar were produced. When two copper points were made the electrodes while under the influence of a powerful electro-magnet, and the battery power intense, the sound produced was so loud as to bear a resemblance to distant discharges of musketry.

The magnet appears to cause these effects by producing a change in the molecular constitution of the matter of the electrode, or rather of the highly diffused matter which forms the voltaic arc.

(134) **Sounds produced in Metallic Wires by the Passage of a Voltaic Current through or round them.**—Bars of *iron*, *tin*, *zinc*, *bismuth*, and even of *lead*, emit distinct sounds when traversed by a current from five to ten pairs of the nitric acid battery, whilst resting on the poles of an electro-magnet; *copper*, *platinum*, and *silver* bars do the same, and *mercury*, and even dilute sulphuric acid and a solution of common salt enclosed in tubes of glass, emit sounds under similar circumstances.

For experiments on the sounds produced in metallic wires by the passage of a voltaic current through or round them, a sounding-board may be employed, on which the wires or rods are kept in a state of tension by a weight; the electric current may be sent through the wire, or through helices of copper wire surrounding but not touching them. The current must not be continuous, but broken at regular intervals. The sound of a well-annealed iron wire, which far surpasses that emitted by any other metal, is very strong, resembling the sound of church bells in the distance. De la Rive suggested that it might perhaps be advantageously employed in the electric telegraph.

The vibratory motion which results from the magnetisation and

demagnetisation of soft iron by the electric current is shown by the following experiment:—

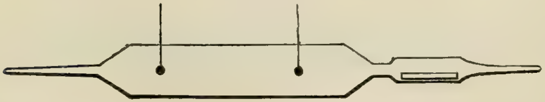
In the interior of a bobbin, or a bottle surrounded with a wire rolled into a helix, are placed some very small discs or filings of iron; when a broken current is caused to traverse the wire of the helix, the discs or filings are seen to be agitated, and to revolve round each other in the most remarkable manner, the filings having the appearance of being in ebullition. If the current be intense, they dart in the form of jets like so many fountains. The motion of the filings is attended with a noise similar to that of a liquid when it is boiling.

To exhibit the heating power of the voltaic arc, a small cavity should be bored in the positive gas-coke electrode, which serves as a crucible (Fig. 175); into this the metal to be operated upon is placed; and the current is transmitted from a battery of twenty or thirty cells of the nitric acid battery. The metals are not only fused, but are actually converted into vapour and disappear.

Fig. 175.

(135) **Luminous Discharge of Voltaic Batteries in Carbonic Acid Vacua.**—The best vacuum procurable by the air-pump is still imperfect, and even in the Torricellian vacuum matter is present in the form of highly attenuated mercurial vapour. Mr. Gassiot, desiring to study the effects of electric discharge through the most perfect medium that could be procured, availed himself (*Phil. Trans.*, vol. cxlix. p. 147) of the powerful affinity of caustic potash for carbonic acid, and with the assistance of Professor Frankland prepared tubes which could be filled with pure carbonic acid gas; then exhausted by means of an air-pump; and finally the small portion of carbonic acid still remaining absorbed by sticks of caustic potash. Several such tubes were provided. They were generally about 6 inches long and 1 inch in diameter;

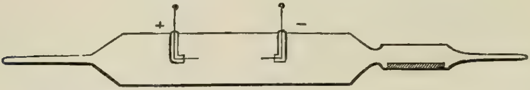
Fig. 176.



some were furnished with gas-coke electrodes in the form of balls $\frac{1}{4}$ inch in diameter, attached to hermetically sealed platinum wires, protected by glass tubing as far as the balls, placed about 3 inches apart, others with copper and platinum electrodes; others were also constructed in which the narrow part of the tube con-

taining the caustic potash was sealed off. On connecting the terminals of a water battery of 3520 elements (102) with the electrodes

Fig. 177.



in any of these tubes, stratified discharges were obtained, which appeared to be continuous, but which entirely ceased when the potash was heated. In one of these tubes the luminous discharge

Fig. 178.

assumed the appearance shown in Fig. 179. With a battery of 512 series of Daniell's elements (zinc and copper insulated), the negative ball was surrounded with a brilliant glow, without any

Fig. 179.

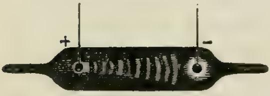


Fig. 180.

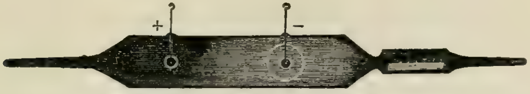
stratification, as shown in Fig. 180; the luminosity round the positive coke being feeble with a battery of 400 series of Grove's elements. The discharge through a vacuum tube 24 inches long and 18 inches in circumference, one of the electrodes being a copper curved disc 4 inches in diameter, and the other a brass wire, passed with a display of magnificent strata of the most dazzling brightness.

'On the copper plate there was a white layer, then a dark space about one inch broad; then a bluish atmosphere, curved like the plate, evidently three negative envelopes on a great scale. When the plate was positive the effect was comparatively feeble.'

Through a vacuum tube 6 inches long and 1 inch in diameter, with the tube containing caustic potash attached, and carbon ball electrodes, intense heat was produced, the discharge presenting a stream of light of intolerable brightness, in which, when viewed through a plate of green glass, strata could be observed. This soon changed to a sphere of light on the positive ball, which became

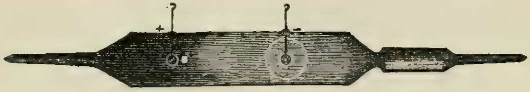
red hot, the negative being surrounded by magnificent envelopes. On applying a horseshoe magnet, the positive light was drawn out

Fig. 181.



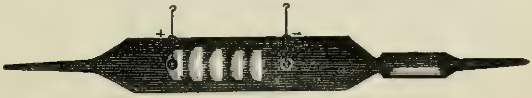
into strata, the needle of a galvanometer in the circuit was violently deflected, and its polarity reversed, settling at a deflection of 45°.

Fig. 182.



On heating the potassa, the discharge again burst into a sunlight flame; and as the heat was still further increased, four or five cloud-like and remarkably clear strata came out from the positive ball;

Fig. 183.



and these were quickly followed by a sudden discharge of the most dazzling brightness, which remained for several seconds. The stratifications were conical in shape, as depicted in Fig. 184. The needle

Fig. 184.

of the galvanometer was suddenly and violently deflected. At the instant that this stratified discharge took place, there was intense chemical action in the battery, denoted by the evolution of nitrous fumes.

With a tube with brass electrodes, the discharge did not appear until the caustic potassa was heated, when the most dazzling strata were observed. 'I had to use a dark-green glass to examine the strata,' says Dr. Robinson. 'As I was observing, the last strata rolled leisurely away, like a globe of light, from the others to the

negative glow, in which it appeared to dissolve. As the potassa cooled, the strata shrunk up and dissolved at the positive wire, as did the glow; and when the dark negative reached the point, all luminosity ceased.'

(136) **Disruptive Discharge before Contact.**—In the course of these experiments, it was ascertained by Mr. Gassiot that a disruptive or spark discharge could be obtained in *air* from the nitric acid battery as well as from the water battery, and that when these discharges were passed through the highly-attenuated matter contained in carbonic acid vacua, the same luminous and stratified appearance was produced as by an induction coil—a proof that whatever may be the cause of the phenomenon, it could not arise from any peculiar action of that apparatus. When the cells of the battery are not insulated, no luminous discharge can be obtained until the circuit has been completed, and the terminals then separated. Upon this the *arc* appears, the length and brilliancy of which depend on the number of elements of the battery. With 400 carefully insulated cells, Mr. Gassiot obtained *spark* discharge *before* the circuit was completed, the spark changing to an *arc* of great brilliancy by a momentary completion of the circuit. With the water battery of 3,520 elements, not the slightest appearance of an arc discharge could be obtained, but a continuous stream of spark discharges took place between the terminals, until the water in the cells had nearly evaporated.

When the discharge from the nitric acid battery between carbon electrodes in the carbonic acid vacuum tubes was *disruptive*, the needle of the galvanometer was only slightly affected, and no chemical action could be observed in the battery; but the instant that arc discharge took place, there was violent deflection of the galvanometer, and strong indications of chemical action in the cells of the battery. Arc discharge could always be produced by heating the caustic potassa. This appeared to facilitate the discharge, and to assist in the disintegration of the carbon particles. It is these carbon particles which produce the arc discharge and the brilliant light.

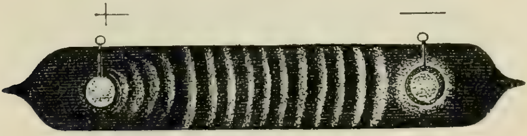
It is Mr. Gassiot's opinion that the stratified discharge arises from the impulses of a force acting on highly-attenuated but resisting media; and he concludes that the ordinary discharge of the voltaic battery under every condition is not continuous, but intermittent, and that it consists of a series of pulsations or vibrations, of greater or less velocity, according to the resistance in the chemical or metallic elements of the battery, or the conducting media through which the discharge passes. (*Proceedings of the Royal Society*, vol. x. p. 404.)

(137) **Further Investigations of Gassiot.**—The stratified appearance produced in carbonic acid vacua by an extended series of the water battery, and the effects obtained by varying the resistance, have been further investigated by Mr. Gassiot (*Proc. Royal Soc.*, Dec. 11, 1862). When the discharge is taken between two small balls of coke, 1½ inch apart, in a carbonic acid vacuum tube, 2½ inches long and 1 inch in diameter, luminous glows are observed on both balls; that on the negative being larger and more brilliant at intervals, as flash discharges take place, but in the dark discharge between the balls no striæ can be seen. When, however, a resistance of about 3 inches of water is introduced in the circuit, the discharge assumes a narrow stratified appearance; it is now intermittent, being separated when examined by the revolving mirror into a series of discharges. By varying the resistance, the character of the discharges could be varied, and rendered either stratified and intermittent, or bright and continuous.

The discharge from the entire battery of 3,360 cells charged with salt and water, between two aluminium balls, three-eighths of an inch in diameter and 3 inches apart, in a vacuum tube about 5 inches long, is cf dazzling brilliancy, exhibiting 12 or 14 striæ, that nearest the negative ball being truncated and of a pale-green colour.

When a resistance of 36 inches of water is interposed in the circuit, a faint luminous discharge is observed at each ball; as the resistance is lessened, the two luminous discharges appear to travel towards or attract each other. When the resistance is diminished to 33 inches, a *single* clearly-defined luminous disc bursts from the positive, and remains steady and apparently fixed.

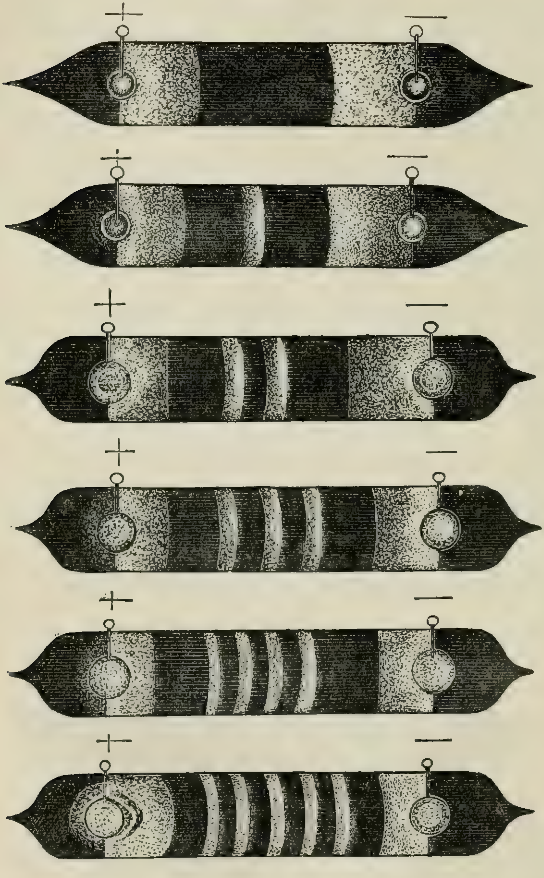
Fig. 185.



The resistance being diminished to 23 inches of water, the luminous discharge at the positive slowly progresses along the tube until a second bright disc appears and remains stationary. The resistance being diminished to 20 inches of water, a *third* disc is developed; 18 inches of water resistance brings out a *fourth* disc; 14 inches a *fifth*; 11 inches a *sixth*; 7 inches a *seventh*, the negative glow increasing in brilliancy, and having a flattened appear-

ance; with 3 inches of water resistance an *eighth* disc is obtained. When the resistance is still further lessened, three or four more discs come out in quick succession; the whole discharge becomes

Fig. 186.



unsteady, and the luminous discs are no longer fixed; some of these remarkable phenomena are illustrated in Fig. 186. When a tube, 3 inches long and 1 inch in diameter, provided with very

thin platinum electrodes, five-eighths of an inch apart, was employed, *no discharge* passed till the potash which it contained was heated, when a faint luminosity appeared, and immediately afterwards one and then two cloudlike striæ came from the positive wire, while round the negative a large brilliant glow was produced; as the discharge continued, the negative wire became red hot.

In this experiment a proof is obtained that the discharge will not pass in a very perfect vacuum, the presence of a certain amount of matter being indispensable, and then heat is developed. The form of the striæ, and the positions they occupy in the vacuum tube, appear to depend—1st, on the power or energy of the battery; 2ndly, on the state of tension of the highly-attenuated matter through which the discharge is visible. The striæ can be controlled, their number increased or reduced, and their places and positions in the tubes altered, by the introduction of a measurable amount of resistance in the circuit; and thus they appear to indicate the amount of force of tension which exists in a *closed* circuit of the battery, as the divergence of the gold leaves of an electroscope denotes the evidence of tension *before* the circuit is completed.

'May not,' enquires Mr. Gassiot, 'the dark bands be the *nodes of undulation*, arising from impulses proceeding from positive and negative discharges, analogous with the stationary undulations which exist in a column of air when isochronous progressive undulations meet each other from opposite directions, and on the surface of water by mechanical impulses similarly interfering with each other? or, can the luminous stratifications be the representations of pulsations which pass through the battery, impulses possibly generated by the action of the discharge along the wires?'

(138) **Heat developed at the Poles of a Voltaic Battery during the Passage of Luminous Discharges in Air and in Vacuo.**—The curious facts—*first*, that when the arc discharge takes place between two wires attached to the terminal plates of an extended series of the voltaic battery, the positive electrode becomes red hot, and ultimately fuses, whilst the negative electrode remains comparatively cool; and, *secondly*, that when the discharge from an induction coil is taken in air or in vacuo, it is the negative terminal that is most heated, were discovered by Gassiot, the former in 1838 and the latter in 1858.

In a paper communicated to the Royal Society (June 12, 1861), he investigates these phenomena more closely. When a vacuum tube, 3 inches long and 1 inch in diameter, provided with carbon ball electrodes, one-eighth of an inch in diameter, and 1 inch apart, is introduced into the circuit of 400 cells of the nitric acid battery, each cell being separately insulated, the discharge at first always assumes the form shown in Fig. 180; the *negative* carbon being sur-

rounded with a luminous glow, which gradually increases in size until the ball becomes red hot. When the carbon ball electrodes are replaced by balls of aluminium, the *negative* metal soon drops off in a molten state, the *positive* ball retaining its original metallic lustre.

In two of the vacuum tubes hollow *brass* balls were substituted for those of carbon. The negative ball soon became heated by the discharge. On a sudden, a flash of light was visible in the vacuum, and the glass became instantly coated with metal. On examining the tube, it was found that one-half of the negative ball was separated from the rest and partly fused : the intense heat had vaporised the silver with which the two hemispheres forming the ball had been soldered, and it was this vaporised metal that was deposited on the sides of the tube.

On repeating this experiment the *negative* ball became, as before, red hot; suddenly a brilliant stratified discharge took place, continuing for three or four seconds; the *negative* ball instantly losing its luminosity, and the *positive* becoming red hot, and remaining so for two or three seconds after the circuit of the battery had been broken. At the moment that the stratified discharge took place the evolution of nitrous fumes denoted intense action in the battery.

It appears, then, that as long as the *intermittent* discharge continues, resistance takes place at the negative terminal, and that this is the cause of its being the more strongly heated ; as soon, however, as the action of the battery becomes sufficiently energetic, *arc* or *continuous* discharge takes place, and then the positive terminal becomes the more heated.

The conclusion drawn by Mr. Gassiot, from these and many other similar experiments, is, '*that the development of heat either at the positive or the negative pole of the voltaic battery is entirely due to the amount of resistance which takes place in that part of the battery circuit.*'

(139) **Interruption of the Voltaic Discharge in Vacuo by Magnetic Force.**—The following beautiful and striking results were obtained by Mr. Gassiot with 400 cells of the nitric acid battery (*Proc. Royal Soc.*, vol. x. p. 269) :—

A large tubular vessel, 24 inches long and 6 inches in diameter at its widest part, was filled with carbonic acid and exhausted, the last portions of gas being absorbed by caustic potash ; through each end of the vessel platinum wires pass ; to one was attached (inside the vessel) a concave copper plate 4 inches in diameter, and to the other a brass wire. This receiver was connected with the battery, and placed between the poles of a powerful electro-magnet, the lines of force going through it. The stratified discharge was extinguished the moment the electro-magnet was thrown into action.

Subsequently, through the sinking of the battery, or some other cause, the stratifications disappeared, and the tube was filled with a luminous glow. On now exciting the magnet with a battery of 10 cells, effulgent strata were drawn out from the positive pole, passing along the upper or under surface of the receiver, according to the direction of the current. On making the circuit of the magnet, and breaking it immediately, the luminous strata rushed from the positive and then retreated, cloud following cloud with a deliberate motion, and appearing as if swallowed up by the positive electrode.

The amount of electricity which passed appeared materially increased on exciting the magnet; once the discharge was so intense as to fuse half an inch of the positive terminal. After this had occurred, the discharge no longer passed as before when the terminals of the battery were connected with it; but on connecting the positive end of the battery with the gas-pipes of the building, the discharge passed. The discharge could also be extinguished by the magnet; and the time necessary to accomplish this furnished a beautiful indication of the gradual rise and reduction in the power of the electro-magnet.

Somewhat similar results were obtained with the water battery, the discharge from 3,520 cells being either entirely destroyed or interrupted by the power of the electro-magnet.

CHAPTER XII.

VOLTAIC ELECTRICITY (*continued*).

MAGNETIC EFFECTS OF THE VOLTAIC CURRENT.

Galvanometers—General Principles—The Astatic Needle Galvanometer—Graduation—The Tangent—Sine—Differential—Reflecting and Marine Galvanometers.

(140) **The Galvanometer.**—The influence of magnetism on the voltaic arc has been already alluded to. The consideration of the mutual relations of the magnetic and electrical forces belongs to another division of our subject. We refer to them here in anticipation, for the purpose of describing some important instruments much used for determining the intensity of hydro-electric currents. These instruments are called *galvanometers* or *galvano-multipliers*, and are founded on the important discovery of Oersted, made in the year 1819.

The fundamental fact observed by this philosopher was, that when a magnetic needle is brought near the conducting medium of a closed voltaic circle, it is immediately deflected from its normal position and made to take up a new one, depending on the relative positions of the needle and wire.

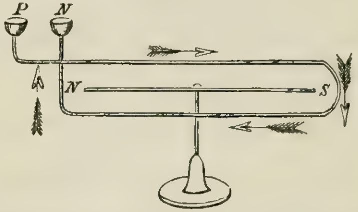
If the connecting medium be placed horizontally *over* the needle, that pole of the latter which is nearest to the *negative* end of the battery always moves *westward*; if it be placed *under* the needle, the same pole moves *eastward.*

If the connecting wire be placed parallel with the needle—that is, brought into the same horizontal plane in which the needle is moving—then no motion of the needle in that plane takes place; but a tendency is exhibited in it to move in a vertical circle, the pole nearest the *negative* side of the battery being depressed when the wire is to the *west* of it, and elevated when it is placed on the *eastern* side.

If the battery current be sent above and below the needle at the same time, but in opposite directions, the deflection is more powerful, for the current traversing the wire *above* the needle conspires, equally with the current passing along the wire *below*, to deflect the needle from its natural position, and to bring it into a new one nearer at right angles to the plane of the wire.

If, instead of passing once over and once under the needle, the conducting wire be caused to make a great number of convolutions, the deflecting power of the current will be proportionately increased, and an instrument will be

Fig. 187.



obtained by which very feeble currents may be readily detected. This then is the principle of the *galvanometer*, the simplest form of which is shown in Fig. 187, but to which, to adapt it to the detection of very minute currents, various forms have been given; in all, the convolutions of the wire are multiplied, and the lateral transfer of the electricity prevented by coating it with sealing wax.

The sensibility of the galvanometer is much increased by neutralising the magnetic influence of the earth, by employing two needles. The neutralising needle is attached to the principal one, placing them one above another, and parallel to each other, but with their poles in opposite directions; they are fixed by being passed through a straw suspended from a thread. The distance between the needles is such as to allow the upper coil of the wires to pass between them, an opening being purposely left, by the separation of the wires at the middle of that coil, to allow the middle of the straw to pass freely through it. A graduated circle, on which the deviation of the needle is measured, is placed over the wire on the upper surface of the instrument, having an aperture in its centre for the free passage of the needle and straw.

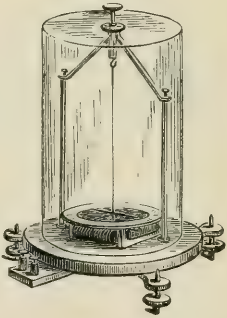
Professor Tyndall (*Heat Considered as a Mode of Motion*, p. 20) gives the following directions for the preparation of a pair of these needles:—

'Magnetise both of them to saturation; then suspend them in a vessel or under a shade, to protect them from air-currents. The system will probably set in the magnetic meridian, one needle being almost in all cases stronger than the other. Weaken the stronger needle carefully, by the touch of a second smaller magnet. When the needles are precisely equal in strength, they will set at *right angles to the magnetic meridian.*

'It might be supposed that when the needles are equal in strength, the directive force of the earth would be completely annulled, that the double needle would be perfectly *astatic* and perfectly neutral as regards direction, obeying simply the torsion of its suspended fibre. This would be the case if the magnetic axes of both needles could be caused to lie with mathematical accuracy in the same vertical plane. In practice, this is next to impossible; the axes always cross each other.'

The astatic needle galvanometer is shown in Fig. 188 The bobbin is surrounded with some two or three thousand turns of very fine and well-insulated copper wire. The needles are suspended by a single fibre of bleached and baked silk. When the instrument is not in use, the upper needle rests on a graduated card, from which it is raised when about to be put in action by a simple mechanical contrivance at the top of the glass shade. The axis joining the two needles must be brought exactly in the centre of the card, which is easily effected by means of adjusting screws. The upper needle is brought exactly to zero of the scale by turning the card by means of a button underneath the base of the instrument. A good galvanometer should not make more than two oscillations a minute, and should return exactly to zero. It is, however, very difficult to realise this. The astatic needle is very sensitive to the slightest magnetic action, and copper wire almost invariably contains traces of iron. Tyndall states that in an instrument constructed for him by Sauerwald, of Berlin, that needle was deflected 30° from the zero line when no current was flowing through the instrument. On replacing the wire by English copper, the deflection fell to 3°; and this deflection was traced to the green silk with which the wire was covered, in the dyeing of which some iron compound had been used. When this was

Fig. 188.



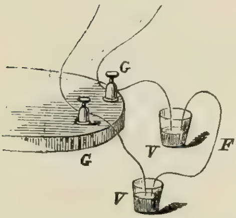
removed and replaced by white silk, a perfect galvanometer was the result.

In his electro-physiological researches, M. du Bois Reymond employed a galvanometer with from 25,000 to 30,000 coils; but to fit it for these delicate investigations, it was necessary to apply a correction for the iron contained in the copper wire. This was done by placing in the interior of the coil a small magnetised fragment one-twenty-fifth of an inch in length; this compensated the disturbing action as long as the needles were near zero, but the action was null as soon as they moved through a few degrees.

(141) **Melloni's Method of Graduating a Galvanometer.**—(Translated from La Thermochrose, and quoted by Tyndall in p. 362 of his work on *Heat Considered as a Mode of Motion*) :—

'Two small vessels, V V (Fig. 189), are half filled with mercury, and connected separately by two short wires with the extremities, G G, of the galvanometer. The vessels and wires thus disposed, make no change in the action of the instrument, the thermo-electric current being freely transmitted as before from the pile to the galvanometer. But if, by means of a wire F, a communication be established between the two vessels, part of the current will pass through this wire and return to the pile. The quantity of electricity circulating in the galvanometer will be thus diminished, and with it the deflection of the needle.

Fig. 189.



'Suppose then that by this artifice we have reduced the galvanometric deviation to its fourth or fifth part—in other words, supposing that the needle, being at 10° or 12° under the action of a constant source of heat placed at a fixed distance from the pile, descends 2° or 3°, when a portion of the current is diverted by the external wire—I say, that by causing the source to act from various distances, and observing in each case the *total* deflection and the *reduced* deflection, we have all the data necessary to determine the ratio of the deflections of the needle to the forces which produce these deflections.

'To render the exposition clearer, and to furnish at the same time an example of the mode of operation, I will take the numbers relating to the application of the method to one of my thermo-multipliers.

'The external circuit being interrupted, and the source of heat being sufficiently distant from the pile to give a deflection not exceeding 5° of the galvanometer, let the wire be placed from V to V; the needle falls to 1·5°. The connection between the two vessels being again interrupted, let the source be brought near enough to obtain successively the deflections—

5°; 10°; 15°; 20°; 25°; 30°; 35°; 40°; 45°.

Interposing after each the same wire between V and V, we obtain the following numbers:—

1·5°; 3°; 4·5°; 6·3°; 8·4°; 11·2°; 15·3°; 22·4°; 29·7°.

Assuming the force necessary to cause the needle to describe each of the first degrees of the galvanometer to be equal to unity, we have the number 5 as the expression of the force corresponding to the first observation. The other forces are easily obtained by the proportions—

$$1{\cdot}5 : 5 = a : x = \frac{5}{1{\cdot}5}a = 3{\cdot}333\,a$$

(that is to say, one reduced current is to the total current to which it corresponds, as any other reduced current is to its corresponding total current), where a represents the deflection when the exterior circuit is closed.

We thus obtain—

5, 10, 15·2, 21, 28, 37·3 ;

for the forces corresponding to the deflections—

5°, 10°, 15°, 20°, 25°, 30°.

In this instrument, therefore, the forces are sensibly proportional to the arcs up to nearly 15°. Beyond this the proportionality ceases, and the divergence augments as the arcs increase in size.

'The forces belonging to the intermediate degrees are obtained with greater ease, either by calculations or by graphical construction, which latter is sufficiently accurate for these determinations.

'By these means we find—

Degrees . . .	13°, 14°, 15°, 16°, 17°, 18°, 19°, 20°, 21° ;
Forces	13, 14·1, 15·2, 16·3, 17·4, 18·6, 19·8, 21, 22·3 ;
Differences . .	1·1, 1·1, 1·1, 1·1, 1·2, 1·2, 1·2, 1·3.
Degrees . . .	22°, 23°, 24°, 25°, 26°, 27°, 28°, 29°, 30° ;
Forces	23·5, 24·9, 26·4, 28, 29·7, 31·5, 33·4, 35·3, 37·3 ;
Differences . .	1·4, 1·5, 1·6, 1·7, 1·8, 1·9, 1·9, 2.

'In this table we do not take into account any of the degrees preceding the 13th, because the force corresponding to each of them possesses the same value as the deflection.

'The force corresponding to the first 30° being known, nothing is easier than to determine the values of the forces corresponding to 35°, 40°, 45°, and upwards.

'The reduced deflections of these three arcs are—

15·3°, 22·4°, 29·7°.

Let us consider them separately, commencing with the first. In the first place then 15°, according to our calculation, are equal to 15·2 ; we obtain the value of the decimal 0·3 by multiplying this fraction by the difference (1·1) which exists between the 15th and 16th degrees, for we have evidently the proportion—

$$1 : 1{\cdot}1 = 0{\cdot}3 : x = 0{\cdot}3.$$

The value of the reduced deflections corresponding to the 35th degree will not therefore be 15·3°, but 15·2° + 0·3 = 15·5°. By similar considerations we find 23·5° + 0·6 = 24·1° instead of 22·4°, and 36·7° instead of 29·7° for the deduced deflections of 40° and 45°.

'It now only remains to calculate the forces belonging to these three deflections, 15·5°, 24·1°, and 36·7°, by means of the expression 3·333 a ; this gives us—

For forces	51·7, 80·3, 122·3 ;
For the degrees . .	35, 40, 45.

Comparing these numbers with those of the preceding table, we see that the sensitiveness of our galvanometer diminishes considerably when we use deflections greater than 30°.

(142) **The Tangent Galvanometer.**—The galvanometer which we have just been describing is an exquisitely delicate test of the existence and direction of a current; it is not, however, adapted for its qualitative measurement; for this purpose the *tangent* compass or galvanometer (Figs 190 and 191) is employed. It consists of a large circle or hoop of copper ribbon covered with silk, fixed vertically upon a graduated circle, exactly in the centre of which is placed—either by suspension by a silk thread, or on a cap resting on a pivot —a very short but intensely magnetised needle, which may be considered to be fully under the influence of the current, at whatever angle it may be placed. The hoop is placed exactly in the magnetic meridian, and when the current is transmitted through it the needle deviates, and the force of the current is proportional to the *tangent of the angle of the needle's declination*, whence the name given to the instrument. The needle is provided transversely with a long light copper needle, by means of which the angle is measured. The tangent of the angle of deflection may be learned without calculation by reference to a Table of Natural Tangents. This instrument cannot be relied upon for angular deviations, which much exceed 70°, owing to the rapidly-diminishing angular deviation produced by equal increments in the force of the current, when the deflec-

Fig. 190.

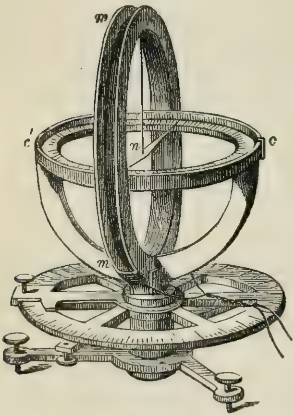
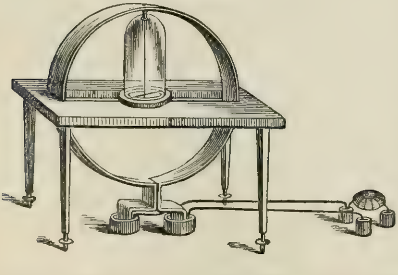


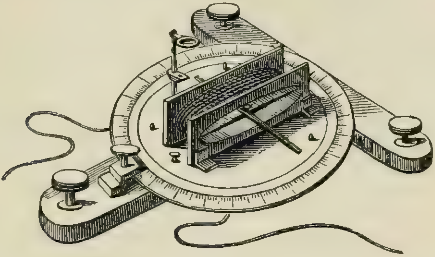
Fig. 191.



tion has reached this extent. By introducing into the same circuit a voltameter and a tangent galvanometer, it is found that the chemical action of the current is proportional to its magnetic action. The galvanometer is, therefore, a measure of the chemical as well as of the magnetic action of a voltaic current.

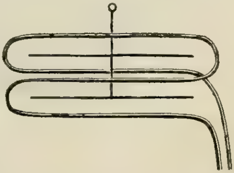
(143) **The Sine Galvanometer.**—This instrument, shown in Fig. 192, consists of a single magnetised needle surrounded with a

Fig. 192.



coil which is movable on its axis; it acts on the principle that *the intensity of the current varies as the sine of the angle of deflection*, and is applicable rather to the determination of the intensity of strong currents than to the detection of weak ones. The instrument is placed in the magnetic meridian, and when the needle is deflected by the current, the coil is turned until it again coincides with the new direction of the needle, the exact parallelism of the needle and coil being determined with the aid of a lens. The number of degrees which it was necessary to turn the coil from the zero point to adjust it to the new position of the needle is read off on the graduated scale surrounding the coil. This is the exact measurement of the angle which the needle forms with the magnetic meridian, and also of the intensity of the current, by which the needle has been deviated; but this is also equal to the horizontal force of terrestrial magnetism, in virtue of which the needle tends to return to the magnetic meridian; and this being equal to the *sine of the angle of deflection*, the intensity of the current is of course the same, and its value may be determined by reference to a table of natural sines.

Fig. 193.



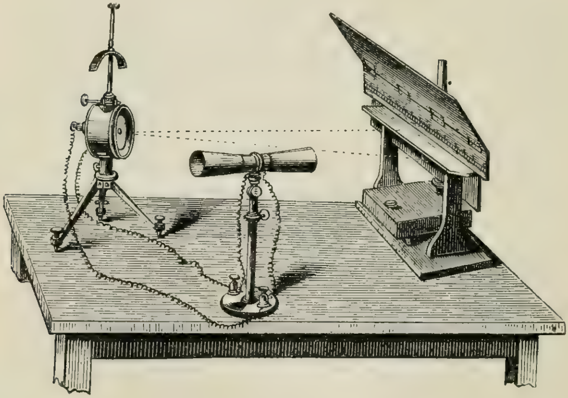
For the detection of currents of small intensity, such as those produced by thermo-electric action, neither of the galvanometers

above described is adapted, the length and thinness of the wire opposing too great a degree of resistance to the passage of such feeble currents. The wire for such purposes should make but few turns round the needle, and should be at least $\frac{1}{30}$ of an inch in thickness; or, as Fechner recommends, should consist of a single strip of copper, and an astatic needle having the freest possible motion (Fig 193).

(144) **The Differential Galvanometer.**—This instrument is used for the determination of the relative force of two currents. It consists of a galvanometer, with two perfectly similar wires wound round the same frame. Now if two currents of precisely the same potential be sent in opposite directions through these wires, the needle will obviously remain at zero; but if one current be more powerful than the other, the needle will move, indicating the stronger current, and showing by the amplitude of the deflection by how much the stronger current exceeds the weaker.

(145) **Thomson's reflecting Galvanometer.**—This instrument is shown in Fig. 194. A small magnet is fixed to the back

Fig. 194.



of a little circular glass mirror, which weighs with the magnet about $1\frac{1}{2}$ grain. It is suspended by a fine silk thread, in a frame which slides in a circular bobbin. This bobbin contains a coil of short and thick wire for thermo-electric experiments, or of long thin wire for chemical currents. The layers of the coil are very close to the magnet, consequently in the position of greatest efficiency. The coil has a small cylindrical opening in the centre, not longer than the circular mirror, in front of which a lens is

placed. A lamp, placed on a separate stand with a slide and scale, throws the light on the mirror, which reflects the rays back through the lens, and this concentrates them into an image of the flame on the scale in front of and over the lamp. The reflected image traverses to and fro on the scale as the magnet and mirror are deflected to the right and left. Owing to the very small angular deflection which suffices to cause the spot to traverse the entire scale, the deflections of this spot may be taken as strictly proportional to the deflecting current.

At the top of the box which encloses the coil is a perpendicular rod, on which at right angles a magnet slides up and down. By means of a tangent and screw arrangement, this magnet can be moved very slightly in a horizontal direction. The object of this magnet is to counteract the influence of the earth's magnetism on the suspended magnet. By lowering or raising the magnet at the top, a spot can be found where the influence of the earth's magnetism is neutralised, and the suspended needle is then in an astatic state.

(146) **Thomson's Marine Galvanometer.**—This instrument allows galvanometric measurements which can be made on land to be repeated at sea. The small magnet and mirror are strung on a strong single fibre of silk, which is stretched in a frame, and secured at top and bottom. The silk fibre must go accurately through the centre of gravity, so that when the frame is moved or inclined, the mirror produces no change by the action of gravitation, or, in other words, without altering the relative positions of the frame and the image on the scale. The effect of the earth's magnetism is equally neutralised—first, by a very stout soft iron box, which contains the coil with the magnet and mirror; and secondly, by a horseshoe magnet inside the iron box, the directing power of which is much stronger than that of the earth.

Galvanometric observations of all kinds can easily be made with this instrument in the roughest weather at sea; neither the continual alteration of the ship's course, nor the motion due to the waves, has any effect on the deflections. The instrument can be made either with differental coils or with simple coils, to be used in connection with Wheatstone's balance, or it will indicate the loss by direct deflection. It may also be used as a receiving instrument for messages, since the movements of the spot of light can be as readily interpreted as those of any single needle receiver.

A jar will not derange the instrument, and there are no metal bearings which can rust. Its practical value is now well known, and has been tested by many years' experience in the hands of various electricians.

CHAPTER XIII.

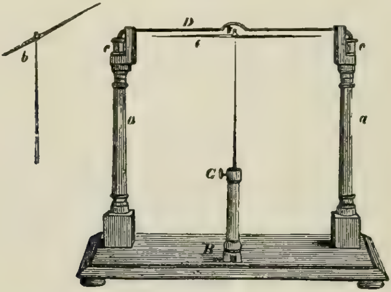
ELECTRO-MAGNETISM.

Discovery—Mutual Actions of Magnets and Movable Conductors—Of Parallel Currents—Laws of Angular Currents—Solenoids—Theories of Magnetism — Faraday's Investigations — Electro-magnetic Rotations — Electro-magnets—Electro-magnetic Engines.

(147) **Oersted's Discovery.**—The grand fundamental fact observed by Oersted, in 1819, was, that when a magnetic needle is brought near the connecting medium (whether a metallic wire, or charcoal, or even saline fluids) of a closed voltaic circuit, it is immediately deflected from its position, and made to take up a new one, depending on the relative positions of the needle and conductor.

In Fig. 195, let D represent a copper wire, the bent ends of which dip into two small cups *c c*, surmounting two wooden pillars *a a*, and filled with mer-

Fig. 195.



cury; let *e* represent a magnetic needle finely balanced on a pointed wire which can be raised or depressed, and adjusted either above or below D by means of the screw C, and let the apparatus be arranged with the wire in the line of the magnetic meridian.

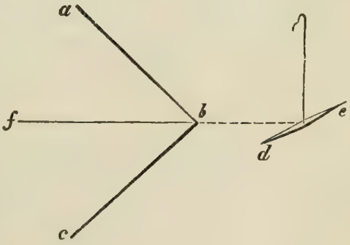
If the connecting medium be placed horizontally *over* the needle, that pole of the latter which is nearest to the *negative* end of the battery moves *westward*; if it be placed *under* the needle, the same pole moves *east.* If the connecting wire be placed parallel with the needle, that is, brought into the same horizontal plane in which the needle is moving, then no motion of the needle in that plane takes place; but a tendency is exhibited in it to move in a vertical circle, the pole nearest the negative side of the battery being depressed when the wire is *west* of it, and elevated when it is placed at the *eastern* side.

In electro-magnetic researches it is necessary to bear in mind these affections of the needle and conducting wire. The following aid to the memory is useful. Let a person suppose himself to be swimming in a river *against* the stream, and looking down upon it; the running stream being the conducting wire, the *north* pole moves to the *left* hand. If he suppose himself to be swimming on his back, and looking upwards on the current, the *north* pole passes to his *right* hand.

The extent of the declination of the needle depends entirely on the *quantity* of electricity passing along the conductor; it has nothing to do with its *tension*, which is probably the reason that the first enquirers failed in discovering the above effects, since they all worked with statical electricity.

(148) **Law of Electro-magnetic Force.**—When the current is rectilinear, and the length of the conducting wire considerable, so that in relation to that of the needle it may be regarded as infinite, the intensity of the electro-magnetic force was shown by Biot and Savary to be '*in the inverse ratio to the simple distance of the magnetised needle from the current*;' but it is only under these conditions that the law is true, for it has been shown by Laplace that the elementary magnetic force, that is, the elementary action of a simple section of the current upon the needle, is, like all other known forces, in the inverse ratio of the *square of the distance*, and proportional to the *sine of the angle* formed by the direction of the current, and by the line drawn through the centre of the section to the centre of the needle. In fact, by calculating, according to this principle, the sum of all the elementary actions that are exercised on a small needle by an indefinite rectilinear current, it is found that the intensity of this resultant should be, as experiment proves it really is, in the inverse simple ratio of the distance.

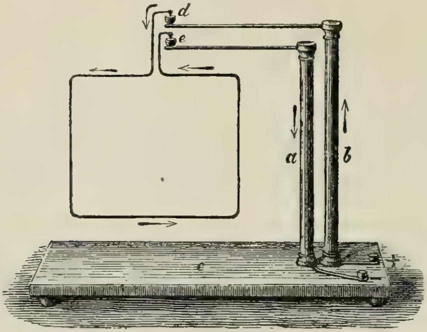
Fig. 196.



From the same law of the elementary force it follows that the intensity of the action of an indefinite angular current, *a b c* (Fig. 196), on a small needle, *d e*, is in the inverse ratio of the distance, *b d*, like that of the rectangular current, but it is moreover proportional to the tangent of half the angle, *a b f*.

(149) **Action of a Fixed Magnet on a Movable Conducting Wire.**—The apparatus shown in Fig. 197 was contrived by

Fig. 197.



Ampère to demonstrate the reaction of the magnetic poles on the electric current:—

Two metallic uprights, *a b*, provided at their lower extremities with cups to hold mercury, are fixed on a base-board *c*; from the tops of these vertical rods proceed long horizontal arms, carrying at their ends brass mercury cups. The movable conductor consists of a rectangular copper wire, its two extremities being brought back near each other, so that their points may dip into the mercury capsules, *d e*: one of the poles of the voltaic battery is made to communicate with the lower extremity of one of the fixed conductors, and the other with the corresponding extremity of the second pillar.

Supposing the connections to be made in the manner indicated in the figure, then the current will circulate through the system in the direction pointed out by the arrows; and on placing a magnetised bar below and very near to the lower part of the wire, the latter immediately moves and sets itself transversely to the magnet. On altering the direction of the current, or on turning the fixed magnet round, the wire again moves and describes an angle of 180°, in order to take up a position the reverse of that which it previously occupied, and which is in strict accordance with Ampère's formula in the case of a fixed current and movable magnet.

If the diameter of the rectangular wire be considerable (from 18 inches to 2 feet), and if it be traversed by a powerful voltaic current, it is acted upon sensibly by terrestrial magnetism, and sets itself transversely or perpendicularly to the magnetic meridian, the earth acting like a magnet whose N. pole would be on the S., and whose S. pole would be on the N. side of the earth.

This phenomenon is, however, better exhibited by an ingenious little apparatus contrived by De la Rive, and shown in Fig. 198:—

The conducting wire is made into a ring, consisting of several coils, well insulated, being wrapped round with silk; one end of the wire is soldered to a zinc plate, and the other to a copper plate, the latter enveloping the former. The little voltaic battery thus formed is placed in a small cylindrical glass vessel, which can be floated in water by a cork attached to its upper end. Dilute sulphuric acid is poured into the cylinder, and it is then placed in a basin of water. By the current of electricity which is determined round the coil, magnetic properties are conferred upon it; it manifests

Fig. 198.

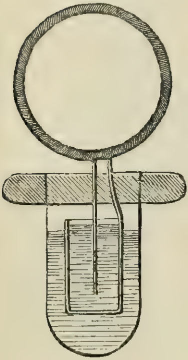


Fig. 199.

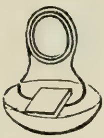
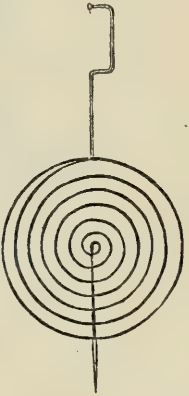


Fig. 200.



a tendency to take a position in the plane of the magnetic meridian, and it exhibits all the effects of attraction and repulsion described above, when a strong bar-magnet is brought near it on either side. The motions of this floating coil are less impeded by setting it afloat in a little varnished wooden dish, as shown in Fig. 199. On pouring dilute sulphuric acid into the little bowl, the coil becomes surprisingly sensible to the influence of a magnet, and will be attracted and repelled at the distance of several inches.

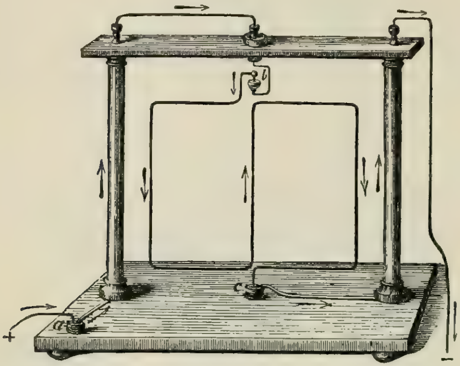
Or—

The wire may be bent into a spiral (Fig. 200), and suspended in such a manner as to allow it free horizontal motion; on passing the voltaic current through it, the plane of the spiral will arrange itself E. and W.; the *positive* current ascending on the W. side and descending on the E., taking the same course as the hands of a watch when it is held on edge, with the plane of the dial lying E. and W. facing S. The side of the spiral which is

towards the N. acts as a N. pole, and the S. side has an opposite polarity. Each side powerfully attracts iron filings.

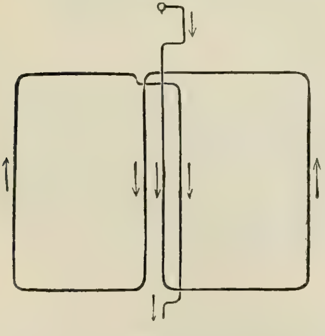
(150) **Mutual Action of Parallel Electrical Currents.**—When two metallic wires are traversed simultaneously by an elec-

Fig. 201.



trical current, the wires are either attracted towards, or repelled from, each other, according to the relative directions of the two currents. When they move in the *same* direction through the wires, there is mutual attraction; when they move in a *contrary* direction, there is mutual repulsion set up between the conductors. These phenomena were discovered by Ampère, to whom is also due the development of the mathematical laws which govern them. They may be experimentally illustrated by the little apparatus shown in Figs.

Fig. 202.

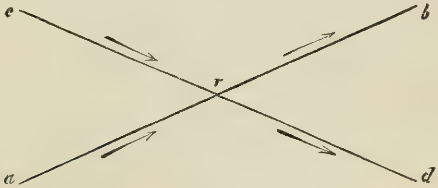


201 and 202. The positive electrode of a battery of 5 or 6 pairs is made to communicate with the left-hand pillar (Fig. 201) through the mercury cup a; the voltaic current ascends this pillar, and enters the movable rectangular copper wire through

the mercury cup *b*, leaves it through the cup *c*, and ascending the right-hand column completes the circuit through a wire communicating with the negative electrode. By observing the direction of the arrow-heads, it will be seen that the voltaic current is moving in different directions through the fixed pillars, and through those portions of the movable conductor adjacent to them; the rectangle is therefore repelled, in accordance with Ampère's law; but by arranging the wire as shown in Fig. 202, the current is caused to move in the same direction through the pillars and the adjacent parts of the movable conductor, and attraction consequently results.

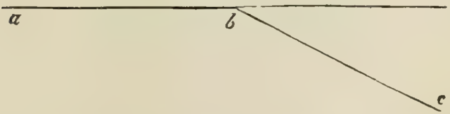
(151) **Laws of Angular Currents.**—Let *a b* and *c d* (Fig. 203) be two currents crossing at the point *r*; there will be attraction

Fig. 203.



between the parts *a r* and *c r*, because the currents are both converging towards *r*, and also between *b r* and *d r*, because they are both diverging from that point; but there will be repulsion between *a r* and *r d*, and also between *c r* and *r b*, because, while *a r* and *c r* are approaching the point *r*, *r b* and *r d* are receding from it. From this it follows that an angular current, *a b c* (Fig. 204),

Fig. 204.

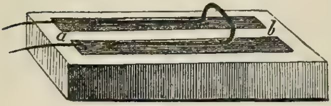


tends to become straight; the parts *a b* and *b c* exercising a mutual repulsion, which not only tends to bend back *b c* into a prolongation of *a b*, but which is still exercised when this condition is fulfilled; in other words, *the contiguous portions of the same rectilinear*

currents repel each other. This important consequence of his theory was demonstrated by Ampère by the following experiment:—

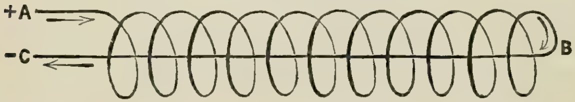
A hollow cut out of a block of wood (Fig. 205) is divided into two compartments by the non-conducting division *a b*; a silk-covered copper wire is so bent that in each compartment it shall present a horizontal branch parallel to the division. These branches or arms are covered with wax, except at their extreme ends, where they are bent so as to touch the mercury. On passing a strong current through the wire it immediately recedes, showing an apparent repulsion between the current passing through the mercury and that traversing the wire.

Fig. 205.



(152) **Sinuous Currents: Solenoids.**—If a current, instead of following a rectilinear course, deviate alternately to the right and to the left, its action is the same with that of a rectilinear current of the same extension. The combination of a rectilinear with a sinuous current is called a *solenoid.* It is a system of circular currents, equal and parallel, formed by twisting a silk-covered copper wire, corkscrew-fashion, back upon itself; but to make it perfect, the straight part of the wire must be as exactly as possible in the centre of the helix. Thus arranged, when the circuit is traversed by a current, the action of the solenoid in the direction of its length A B (Fig. 206) is destroyed by that of the

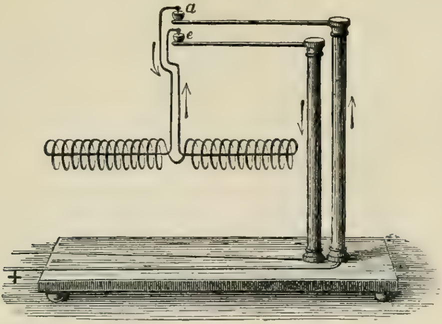
Fig. 206.



rectilinear current B C; and the only effect produced is due to the system of circular currents, equal and parrallel, moving in a direction perpendicular to its axis. Now, as the action of fixed currents on movable ones is to bring them into a position parallel to themselves, with their currents moving in the same direction, a solenoid freely suspended on a vertical axis should, when acted on by a rectilinear current, range itself with its circles parallel to that current. It is accordingly found that on passing a strong voltaic current through a solenoid suspended from two mercury cups (as shown in Fig. 207), so as to allow it perfect freedom of motion round a vertical axis, and passing at the same time underneath and parallel to its axis a rectilinear current, the solenoid turns

itself across that current, taking up a position with its circles parallel to it.

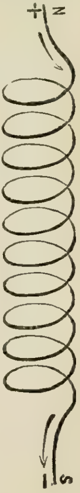
Fig. 207.



If instead of passing the rectilinear current *horizontally* underneath the solenoid, it be passed vertically and near one end, the latter is either attracted or repelled, according as the currents are passing in the same or in opposite directions through the wire, and through the contiguous parts of the solenoid. Two solenoids exhibit towards each other the phenomena of attraction and repulsion in a manner precisely similar to two magnets, and a solenoid is influenced by a magnetic bar precisely as another magnet would be. In short, a solenoid has all the properties of a magnet, and when suspended (as in Fig. 207), and traversed by a strong electric current, it will range itself with its axis parallel to the axis of the declination needle. If the helix be *dextrorsal*, its coils moving upwards from left to right (Fig. 208), the S. pole will be at the end at which the current enters; if the helix be *sinistrorsal*, its coils moving upwards from right to left (Fig. 209), the N. pole will be at the end at which the current enters.

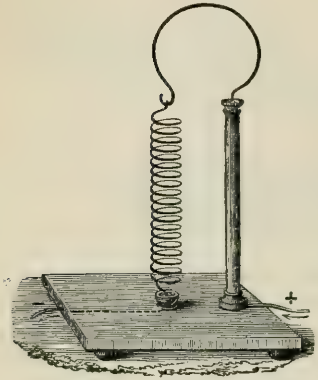
Fig. 208.

Fig. 209.



A good illustration of the mutual attractions of conducting wires carrying voltaic currents moving in the same direction, is afforded by Roget's spiral (Fig 210). The helix is held either by a screw or by a fine wire immediately over a cup of mercury, into which its opposite end just dips. On passing the current down the wire, the coils, being all traversed in the same direction, mutually attract each other; the entire spiral is hereby shortened, and the lower end leaves the mercury; contact with the battery is thus broken. The spiral resumes its former length, and the end again touches the mercury, but this causes a re-establishment of the current and a re-shortening of the spiral; in this way a rapid series of horizontal vibrations is produced.

Fig. 210.



(153) **Theories of Magnetism: Œpinus, Coulomb.**—The first rational theory that was devised to account for the phenomena of magnetism was that of Œpinus (1759), who applied the electrical theory of Franklin with great ingenuity. This theory includes the four following propositions:—

1. In all magnetic bodies there exists a substance which may be called the magnetic fluid, whose particles repel each other with a force inversely as the distance.

2. The particles of this fluid attract the particles of iron, and are attracted by them in return with a similar force.

3. The particles of iron repel each other according to the same law.

4. The magnetic fluid moves through the pores of iron and soft steel with very little obstruction; but its motion is more and more obstructed as the steel increases in hardness and temper, and it moves with the greatest difficulty in hard-tempered steel and ores of iron.

The laws of attraction and repulsion find a satisfactory explanation on this hypothesis, but it fails when applied to the consequences which follow on the division of a magnetic bar; each piece should have a different and distinct polarity, whereas it is well known that each fragment is a bi-polar magnet. Œpinus endeavoured to overcome this difficulty by supposing that during the act of fracture, the balance of magnetic force was disturbed,

and that a portion of the fluid escaped from the overcharged pole, while another portion entered into that which was undercharged.

The theory of two magnetic fluids was advocated by Coulomb. A magnet was considered as composed of minute invisible particles of iron, each of which has individually the properties of a magnet. It was assumed that there are two distinct fluids, the *austral* and *boreal*; and under the influence of either in a free state, the bar would point to the N. or S. poles of the earth, according to circumstances. It was supposed to be within these small particles or metallic elements that the displacement or separation of the two attractive powers takes place, and that the particles may be the ultimate atoms of iron.

A magnetic bar may, according to this theory, be represented (Fig. 211) as composed of minute portions, the right-hand ex-

Fig. 211.

tremities of each of which possess one species of magnetism, and the left-hand extremities the other. The shaded ends being supposed to possess *boreal* and the light ends *austral* magnetism, then the ends of the bar itself, of which these sides of the elementary manget form the faces, possess respectively *boreal* and *austral* magnetism, and are the boreal and austral poles of the magnet.

In ordinary iron these fluids exist in a combined state, and are therefore perfectly latent, the metal appearing to be distitute of magnetism. They exist in certain proportions united to each molecule or atom of the metal, from which they can never be disunited ; the only change which they are capable of undergoing being their decomposition into the separate fluids, one of which, in a permanent magnet, is always collected on one, and the other on the opposite side of each molecule.

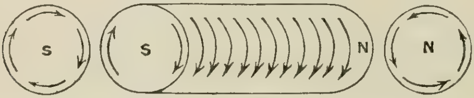
(154) **Ampère's Electro-dynamic Theory.**—Each particle or magnetic element is regarded as constituting a voltaic circuit, and a magnet is composed of an assemblage of parallel filaments, each of which is made up of a series of particles, round which electric currents are circulating, in the same direction with reference to the axis of the filaments, and moving in planes perpendicular to that axis.

In a bar of unmagnetised iron the electricity is supposed to be in a latent state. In a magnetised bar that extremity of the mag-

netic filament in which, when uppermost, the current is moving in the same direction as the hands of a watch, has the properties of a S. pole, and *vice versâ.*

If the filament be placed horizontally (Fig. 212), its N. pole pointing to the N. and its S. pole to the S., the electric currents circulate on the upper side, from W. to E., and downwards on the eastern side; on the under side from E. to W., and upwards on the western side.

Fig. 212.



The mutual repulsion of two magnetic poles of the same name, and the attraction of two dissimilar poles, are simple consequences of this theory. It has been shown that there is a repulsive action set up between two wires along which electrical currents are moving in opposite directions, but that when the currents move in the same direction along each wire attraction results.

Now it is easy to see, that when two similar magnetic poles are

Fig. 213.

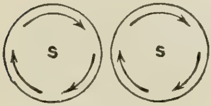
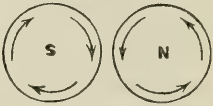
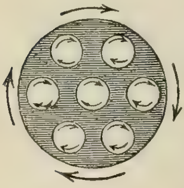


Fig. 214.



brought near each other (Fig. 213), the hypothetical currents are moving in contrary directions at the sides contiguous to each other, and that when two dissimilar poles are approximated (Fig. 214) the currents are flowing in the same direction—hence repulsion in the former case, and attraction in the latter.

Fig. 215.

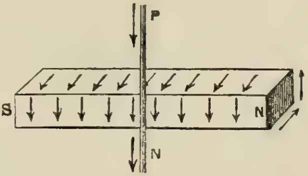


It follows also, as a consequence of this mutual action of currents, that, viewing a magnet as an assemblage of filaments round each of which electrical currents are circulating, the resultant action of the magnet can only be exerted externally: for let Fig. 215 represent the action of a cylindrical magnetic bar, and the small included circles some of its filamentary elements, the currents moving round the contiguous sides of any two of these circles, being opposed in direction, neutralise

each other; while the currents that pass near the circumference are not so compensated by others, and their action is therefore fully exerted on external bodies.

Again, the tendency of a magnet and conducting wire to place themselves at right angles to each other is referred by this theory to the transverse movements of the electric currents in the magnet, which act upon the current in the conductor and are also acted upon by that current. Thus let S N (Fig. 216) represent a magnet, and P N a wire conveying a current of electricity; the arrow-heads show the direction in which the currents are moving round the magnet, viz. in planes perpendicular to its axis; the wire P N tends to range itself, therefore, transversely to the axis of the bar, in order that the current moving along it should be parallel to that of the current in the nearest part of the magnet.

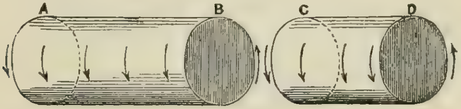
Fig. 216.



Further, the theory happily explains the induction of an opposite polarity in the adjacent end of a piece of soft iron by a magnetic pole.

Thus let A B (Fig. 217) be the magnet, and C D the bar of iron;

Fig. 217.



the former has a tendency to excite in the latter a current of electricity circulating in the same direction as the currents moving round its own filaments; but it is evident that if the current at the end of B revolves, as seen by a spectator looking at that end from right to left, the current induced at the end of the iron bar (C) revolving in the same direction in space, will appear to the spectator looking at that end to move from left to right; and as the polarity depends upon the direction of the current with respect to the axis at the extremity, the polarity of B will be the reverse of that at C, and the same as that of D, but the polarities of C and A will be the same. Precisely the same consequences must follow upon the

fracture of a magnetic bar; each piece becomes a perfect magnet, the polarities of the fractured ends being opposed to each other.

This theory, which is sustained by the highest mathematical investigation, furnishes a satisfactory explanation of all the mutual actions of magnets and electric currents, and of magnetic and electro-magnetic phenomena in general. As laid down by Ampère, however, it fails to account for *diamagnetic* actions. To render it at all consistent with these, it has been assumed that electric and magnetic forces might, in diamagnetic matter, induce currents of electricity in the direction the reverse to those in magnetic matter, or else might induce currents where before there were none; whereas in magnetic cases, it was supposed that they only constrained particle currents to assume a particular direction, which before were in all directions. Others, amongst whom is Weber, have made an addition to the hypothetical views of Ampère —viz. that there is electricity among the particles of matter which is not thrown into the form of a current until the magnetic induction comes upon it, but which then assumes the character of a current, having a direction contrary to that of the currents which Ampère supposed to be always circulating round magnetic matter, and so those other matters are rendered diamagnetic.

A striking experimental distinction between a magnet and a helix, through which a current of electricity is circulating, has been pointed out by Faraday (*Ex. Resear.*, 3,273), viz.:—

'Whereas an unchangeable magnet can never raise up a piece of soft iron to a state more than equal to its own, a helix can develope in an iron core magnetic lines of force of a hundred or more times as much power as that possessed by itself when measured by the same means.'

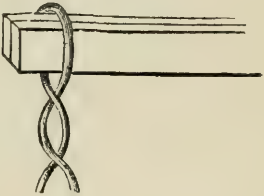
De la Rive (*Notices of the Meetings of the Royal Institution*, vol. i. p. 458) suggests that the views of both Ampère and Weber may be maintained, by supposing that all atoms of matter are endowed with electrical currents of a like kind, which move about them for ever, without diminution of their force or velocity, being essentially part of their nature. The direction of these currents for each atom is through one determinate diameter, and may therefore be considered as the axis. When they emerge from the body of the atom they divide in all directions, and running over every part of the surface, converge towards the opposite end of the axis diameter, and therefore re-enter the atom to run for ever through the same course. The converging and diverging points are, as it were, poles of force.

Where the atoms of matter are close or numerous in a given space, the hypothesis then admits that several atoms may conjoin into a ring, so that their central or axial currents may run one

into the other, and not return, as before, over the surface of each atom. These form the *molecules of magnetic matter*, and represent Ampère's hypothesis of molecular currents. When the atoms, being fewer in a given space, are farther apart, or where, being good conductors, the current runs as freely over the surface as through the axis, then they do not form like groups to the molecules of magnetic matter, but are still considered subject to a species of induction by the action of external magnets and currents, and so give rise to Weber's reverse currents.

(155) **Faraday's Investigations.**—To test and measure the magnetic forces, Faraday employed the induced magneto-electric current. The amount of current induced he found to be precisely proportionate to the amount of lines of magnetic force (65, 4), intersected by a moving wire, in which the electric current is generated and appears. Thus on introducing a bar-magnet into the loop (Fig. 218), and leaving it there, a deflection of 8° was constantly produced at the galvanometer; *two* introductions (the electric current being broken by removing one or other of the terminals of the loop from the mercury cup of the galvanometer previous to removing the magnet) produced a deflection of 15·75°; three, 23·87°; and four, 31·66°.

Fig. 218.



The magnetic forces are distributed in and round a bar-magnet in the simplest and most regular manner, so that any wire or line proceeding from a point in the magnetic equator of the bar, so as to pass through the magnetic axis to a point on the opposite side of the magnetic equator, must intersect *all* the lines in the plane through which it passes; and a wire proceeding from the end of a magnet at the magnetic axis to a point in the magnetic equator, must intersect curves equal to half those of a great plane, however small or great the length of the wire may be. But a wire from pole to pole, passing close to the equator, has no electric current induced in it when revolved round the magnet, because it intersects half of the external lines of force in a great plane *twice in opposite directions.*

When wires of different metals are moved across the lines of force of a magnet, the currents induced in these different bodies are proportional to their electro-conducting power. Thus loops of—

Copper wire deflected the galvanometer			. . .	63·0°
Silver	,,	,,	,, . . .	61·9
Zinc	,,	,,	,, . . .	31·5
Tin	,,	,,	,, . . .	19·1
Iron	,,	,,	,, . . .	18·0
Platinum	,,	,,	,, . . .	16·9
Lead	,,	,,	,, .	12·1

By the term '*magnetic polarity*,' Faraday understands 'the opposite and *antithetical* actions which are manifested at the opposite ends of a portion of a line of magnetic force.' But this cannot be correctly exhibited in every case by attractions or repulsions, which are affected by circumstances. In a field of equal magnetic force a magnetic needle can show no polarity, as the very fact of pointing implies the disturbance of the equality of arrangement of force. A wire, however, moving across the line of force shows the full amount of magnetic power without in the least disturbing the disposition of the power.

To these lines of magnetic force Faraday assigns a true physical character. They are essentially *dual* in their nature, the two opposite magnetic forces being mutually related; and as in static electrical induction one electricity cannot exist without a relation to equality with, or dependence on, the other, so in magnetism an absolute charge of N. or S. polarity is also an impossibility. In a bar-magnet the outer forces at the poles are related to each by curved lines through space, and although by approaching a second magnet the disposition of those second lines may be changed, yet their sum remains unaltered. That the lines of force are closed, curves passing in one part of their course through the magnet, and in the other part through the space around it, is proved by the moving wire; and this fact is considered by Faraday as implying that such lines have a physical existence.

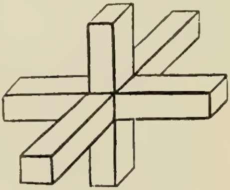
(156) **Analogy between the Electric and Magnetic Forces.**—As far as regards the disposition of the *external* lines of force, the analogy between a magnet and an insulated voltaic battery is perfect; but in the battery the lines of force are not continued *internally*, as is the case with a magnet; consequently, on separating the battery in the middle no charge appears there, nor any origin of new lines of inductive force, but the two divided portions remain in opposite states, or absolutely charged; in the magnet, on the other hand, there is on division a development of new external lines of force, and no absolute charge of *northness* or *southness*, because the lines of force are continuous through the body of the magnet.

It has been shown by Ampère and Davy that an electric current

has a tendency to *elongate* itself, but a magnetic 'axis of power' has a tendency to *shorten* itself; again, *like* electric currents attract each other, but *like* magnetic lines of force exercise mutual repulsion. Now these tendencies seem at first not analogies but contrasts, but they coincide when it is considered that the two axes of power are at right angles to each other, and viewed in this way the probable *oneness* of condition of the electric and magnetic forms of power appears in abundant instances. Thus, unlike magnetic lines when *end on*, as when similar poles are face to face, *repel*; unlike electric currents, when in the same relation, *repel* also; *like* magnetic forces, when *end on*, *coalesce; like* electric forces do the same; *like* electric currents, end to end, do not add to their sums; the quantity of electricity circulating in a battery is not increased by adding to the number of the plates; and *like* magnetic lines of force do not increase each other; lastly, *like* currents side by side (a voltaic battery with large plates compared with one with small plates) add their quantities together, and *like* magnetic forces do the same.

(157) **Places of no Magnetic Action.**—Faraday arranged six electro-magnets, so that their *like* poles were together in such a manner as to include a cubical chamber (Fig. 219); in this chamber he hung a small magnetic needle, but neither it, nor a crystal of bismuth, gave any indications of magnetic power; iron filings sprinkled on a card were introduced, but they were not affected at the middle part, but only near the partly open angles. A ring helix of many convolutions was likewise rotated in this chamber, but no inductive current was manifested by a delicate galvanometer with which it was connected. The cubical space included by these similar poles was, therefore, perfectly destitute of magnetic properties, though surrounded by a high intensity of magnetic power; its condition was analogous to that of the space presented within a metallic globe or cylinder charged with electricity; and as in this case there is no electricity *within* the globe or cylinder, because that necessary connection and dependence of the electric *duals* which is essential to their nature cannot be, so in the case of the magnet, there is no appearance of magnetic force in the cubical chamber, because the *duals* are not both there at once, and one cannot be present without the other. A bar-magnet, according to Faraday's view, is a source of dual power; its dualities

Fig. 219.



being especially related to each other, and incapable of existing but by that relation, which externally is through the space around the magnet, and consists of closed curves of magnetic force. That the space is not magnetically *dark* is proved by the fact, that when it is occupied by bodies such as copper, mercury, &c., they produce magneto-electric currents when moved. The same magnet can hold different charges, as the medium connecting its poles varies; and so, one fully charged with a good medium (such as iron) between its poles, falls in power where the iron is replaced by air, or by space, or by bismuth. The magnet could not exist without a surrounding medium or space, and would be extinguished if deprived of it, and *is* extinguished if the space be occupied adversely by the dual power of a dominant magnet of sufficient force. The polarity of each line of force is in the same direction throughout the whole of its closed course. Pointing in one direction or another is a differential action due to the convergence or divergence of the lines of force upon the substances acted on, according as it is a better or worse conductor of the magnetic force (*Phil. Trans.*, Feb. 1855).

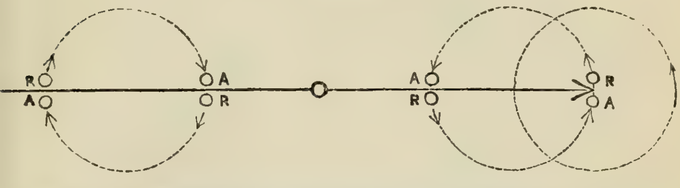
(158) **Faraday's Preliminary Experiments on Electro-magnetic Action.**—Whilst engaged on experiments to ascertain the position of the magnetic needle relative to the conducting wire, Faraday (*Quart. Jour. of Science*, vol. xii. p. 74) was led to some new views of electro-magnetic action. On placing the wire perpendicularly, and bringing the needle towards it to ascertain the attractive and repulsive positions with regard to the wire, he found them to be *eight—two* attractive and *two* repulsive for each pole. Thus allowing the needle to take its natural position across the wire, and then drawing the support away from the wire slowly, so as to bring the N. pole for instance nearer to it, there was attraction, as was to be expected; but on continuing to make the needle come nearer to the wire, repulsion took place, though the wire was still on the same side of the needle. If the wire was on the other side of the same pole of the needle, it repelled it when opposite to most parts between the centre of motion and the end, but there was a small portion at the end where it attracted it.

On making the wire approach perpendicularly towards one pole of the needle, the pole passed off on one side in that direction which the attraction and repulsion at the extreme point of the pole gave; but if the wire were made continually to approach the centre of motion by either the one or the other side of the needle, the tendency to move in the former direction diminished. It thus became null, and the needle was quite indifferent to the wire; ultimately the motion was reversed, and the needle powerfully

endeavoured to pass the opposite way. From this it was evident that the centre of the active portion of either limb of the needle (or the true pole, as it may be called) is not at the *extremity* of the needle, but may be represented by a point generally in the axis of the needle at some little distance from the end. It was evident, also, that this point had a tendency to revolve round the wire, and necessarily therefore the wire round the point; and as the same effects in the opposite direction took place with the other pole, it was evident that each pole had the power of acting on the wire by itself, and not as any part of the needle, or as connected with the opposite pole.

In Fig. 220, sections of the wire in its different positions to the

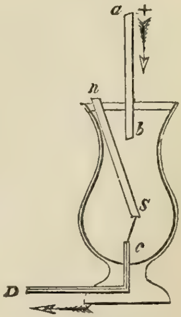
Fig. 220.



needle are represented—the active poles by two dots, and the arrow-heads show the tendency of the wire in its positions to move round these poles.

From these facts, it follows that both attraction and repulsion of conducting wires are compound actions; that there is no attraction between the wire and either pole of the magnet; and that the wire ought to revolve round the magnetic pole, and the magnetic pole round the magnet.

Fig. 221.



(159) **Electro-magnetic Rotations.**—By the following experiments Faraday proved this to be really the case:—

(*a*) *Rotation of a Magnetic Pole round a Conducting Wire.*—The magnet *n s* (Fig. 221) is attached by a thread to the bent copper wire D *c*, which passes through the bottom of a cup nearly filled with mercury; *a b* is another copper wire through which a voltaic current may be transmitted through the mercury. If the current be made to descend, the N. pole of the magnet begins to rotate round the wire *a b*, passing from E through S to W, that is, in the direction of the hands of a watch; but if the current ascends, the line of rotation is reversed.

(*b*) *Rotation of a Conducting Wire round a Magnet.*—This is realised by

the little apparatus shown in Fig. 222. The magnet passes through the bottom of a wooden cup containing mercury, its pole just rising above the surface of the metal. A glass cylinder is cemented into the cup, on the top of which is a wooden cap surmounted by a mercury cup; a wire passes through the bottom of this cup having a hook at the end, from which depends the conducting wire. On transmitting the current through this movable conductor, it immediately begins to revolve round the magnetic pole. Both phenomena may even be exhibited in the same apparatus; and if both magnet and conducting wire be made movable, both will revolve in the same direction round a common centre of motion, each appearing to pursue and be pursued by the other.

Fig. 222.

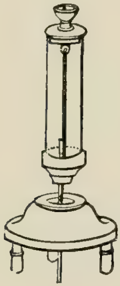
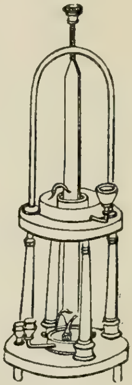


Fig. 223.



(*c*) *Rotation of a Magnet round its own Axis.*—To effect this, the current after traversing one half of the magnet must be diverted from its course and made to pass away in such a direction so that it shall not affect the lower half. The reason for this is evident. Suppose, e.g., a current be made to descend a magnet placed vertically, its N. pole being uppermost, it would tend to urge that pole round from left to right; but its influence on the S. pole would be just the reverse, tending to urge it from right to left.

Ampère was the first to demonstrate the rotation of a magnet round its own axis. A convenient apparatus for the purpose was contrived by Mr. Watkins, and is shown in Fig. 223. The magnet is finely-pointed at each end; the lower point rests in an agate cup; the upper end turns in a hole made in a vertical screw with a milled head to turn it by. The current is transmitted through the lower half of the magnet by establishing communication between the two terminals of the battery and the two mercury cups, shown in the figure. These mercury cups are in metallic connection with circular cisterns containing mercury, into which bent wires attached to the magnet dip.

(*d*) *Rotation of a Conducting Body round its own Axis.*—Two circular wooden troughs are firmly fixed by screws on the arms of a strong horse-

shoe magnet (Fig. 224). These troughs are filled with mercury. Into holes in the centre of the ends of the magnet two conical wires are inserted which are affixed in the centre of two hemispherical cups united to copper cylinders, the wires of which are formed into points which dip into the mercury contained in the circular troughs. Upon the top of each hemisphere is a metallic cup to hold mercury. Other cups for holding mercury are supported on the external ends of bent wires, which pass through the sides of the circular troughs into the mercury contained therein. On transmitting the voltaic current *down* the two cylinders, they immediately commence revolving in opposite directions; but if the two upper cups be united by a wire, and the lower cups connected with the opposite ends of the battery, the

Fig. 224.

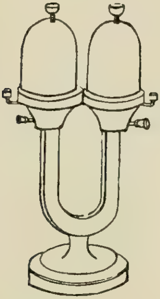
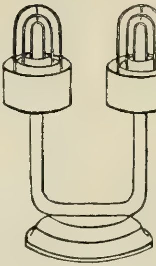


Fig. 225.



same current will traverse both sides of the apparatus, up one cylinder and down the other, and the rotations will now, from the contrary influence of both poles, be in the same direction in both cylinders.

(*e*) *Rotation of a Voltaic Battery round the Pole of a Magnet.*—It is not the wire only connecting the terminal plates of a voltaic battery that possesses electro-magnetic properties; the magnetic needle is equally affected when suspended over the battery itself, or, in other words, every part of the circuit exhibits the same electro-magnetic properties; and as action always implies equal and corresponding reaction, the magnet may be supposed to have a tendency to move the battery, equal to that which the battery has to move it. This tendency was first demonstrated by Ampère in the manner shown in Fig. 225, where a small cylindrical double copper vessel is represented as poised on either pole of a strong horseshoe magnet; each copper vessel contains an open cylinder of zinc, poised on points on the arms of the copper vessels. On pouring dilute sulphuric acid into the copper cylinders, all four commence revolving on their axes, the copper vessels in opposite directions, and each zinc cylinder in a contrary direction to the copper in which it is inserted.

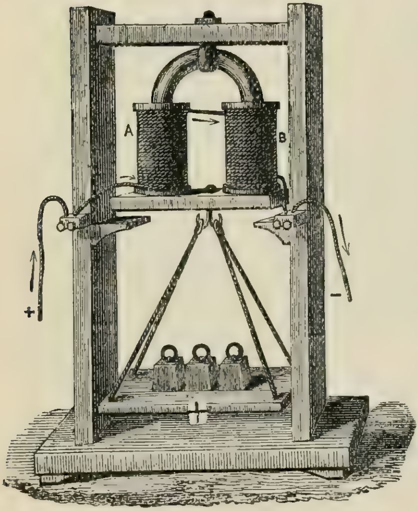
(160) **Magnetic Properties of the Voltaic Current.**—The wire connecting the extremities of a voltaic battery possesses the power of attracting iron filings during the time the current is passing through it, and small needles laid across the wire become

permanently magnetised. In order to give the current its full magnetising efficacy, it should be made to pass transversely round the iron or steel; it should surround it in the form of a helix. Here again we find the polarity given to the needle to depend on the direction of the turns of the helix. If it be *dextrorsal*, the N. pole is formed at the end at which the current enters; if the helix be *sinistrorsal*, the S. pole is formed at that end.

The magnetising power of the current is exerted instantaneously, the steel bar acquiring the utmost magnetism it is capable of receiving the moment the circuit is completed. The application of the helix to the magnetising of large steel bars, by Elias of Haarlem, has been alluded to in a previous chapter (64, 6). By employing a band-spiral of copper instead of a helix, Böttger (*Pogg. Ann.*, vol. lxvii. 115) magnetised to saturation a bar of hard cast-steel, weighing 6 lbs., by merely passing the spiral once backwards and forwards along the bar.

(161) **Electro-magnets.**—When bars of soft iron are submitted to the influence of the voltaic current, they acquire a very high degree of magnetism; but the *coercitive* force—that is, the force in a magnetic substance which opposes the separation of the two magnetic fluids, and their recombination when separated—being in soft iron very small, the magnetism is only temporary.

Fig. 226.



The ordinary arrangement of the horseshoe electro-magnet is shown in fig. 226. The copper wire, which for large bars should be very stout and well covered with silk, is wound a great number of times round the two arms, so as to form two bobbins, A and B. It must turn in the same direction round each bobbin, in order that the two extremities of the bar should acquire opposite polarities. The power varies with the size

of the cylinder, the intensity of the current, and the thickness of the copper wire.

With regard to the thickness of the iron bar, the power of the electro-magnet to deflect a magnetic needle was found by Dub to be proportional to the square root of the diameter of the cylinder, and its lifting power in proportion to its simple diameter.

The laws which govern the forces of electro-magnets have been investigated by Lenz, Jacobi, and Müller.

Let M denote the magnetic force of the electro-magnet:
n the number of convolutions of wire:
d the diameter of the soft-iron wire:
Q the quantity of electricity in circulation:
and c a constant multiplier:

then

$$M = c\, n\, Q \sqrt{d}$$

This law only holds good for bars of iron whose length is considerably greater than their diameter; for feeble currents of electricity; and under the supposition that the number of convolutions of wire is not so great as materially to diminish the influence exercised by the outer coils upon the bar of iron. These conditions are fulfilled in the electro-magnets used for telegraphic purposes.

It will be noticed in the above formula that M increases directly as Q and as n, but Q decreases as n decreases, supposing the electric force to remain constant. Hence it is evident that a certain proportion between the resistance of the wire and that of the remaining portions of the circuit must be preserved, to obtain the maximum magnetic force. This relation is found to be the following:—

'When the resistance of the coils of the electro-magnet is equal to the resistance of the rest of the circuit, i.e. the conducting wire and battery, the magnetic force is a maximum.'

The experiments of Pfaff gave him the following results (Peschel):—

1. The amount of suspensive force is immediately dependent on the intensity of the electric current which circulates about the iron; and the intensity of the magnetism excited in the soft iron is exactly proportional to that of the electric current.

2. The intensity of the current continuing the same, the magnet's suspensive power increases with the number of turns made by the wire, or the total effect of all the coils is equal to the sum of their effects if taken singly.

3. The attractive force of an electro-magnet increases as the mass of the iron composing it, and this increase is proportional to the diameter of the iron cylinder, their lengths being equal.

4. The purer and softer the iron, and the more homogeneous the mass, the stronger the magnetism it is capable of receiving.

5. The form of the iron influences its suspensive power. Cylinders carry greater weights than rectangular bars; and a hollow cylinder from which

a portion has been cut away, so as to form a long horseshoe magnet when viewed in the direction of its axis, but a very short one if taken as to its height, is capable of receiving a very great suspensive force ; and, lastly, a slight curvature of the polar surface adds considerably to its power.

Instead of coiling the wire round the bobbins in one continuous length, it is better that the total length of wire intended to be used should be cut into several portions, each of which, covered with silk or cotton, should be coiled separately on the iron; the ends of all the wires are then collected into separate parcels, and made to communicate with the battery, care being taken that the current shall pass along each wire in the same direction.

With regard to the retention of power by an electro-magnet after the voltaic current has ceased to pass through the helix surrounding it, it was discovered by Ritchie that when the electro-magnet is very short, and the poles near each other, the retaining power with good soft iron is exceedingly small, but that when the magnet is very long the retaining power is considerable. He found also that a *short* electro-magnet, though its lifting power may be considerable, is incapable of inducing permanent magnetism on an unmagnetised horseshoe of tempered steel; while an electro-magnet of four feet in length, though of no greater lifting-power than the small one, is capable of inducing a very considerable permanent effect.

(162) **Sounds produced during the Magnetisation and Demagnetisation of Iron.**—This is best observed by resting the end of a long iron bar, surrounded with a coil of covered copper wire, on a sounding-board; it thus becomes a musical note, and may be heard distinctly through a large room. By suspending an iron bar so that it could vibrate freely, and circulating the voltaic current by a wire so arranged as not to touch the bar, and breaking and renewing battery-contact rapidly, Beatson elicited sounds as loud and distinct as those from a small bell. He ascertained that at the moment the sound is produced, the metal undergoes a sudden expansion, and that on interrupting the current a sudden contraction takes place, this expansion and contraction being independent of that produced by the heating-power of the current. The effects are evidently caused by a molecular disturbance of the particles of the metal by the magnetic inducing influence of the current. This is well shown by an experiment arranged by Grove, in which a glass tube, open at both ends, but protected along its length with a copper jacket, is filled with water in which is suspended powdered magnetic oxide of iron. On looking through the tube at distant objects, a considerable portion of the light is interrupted by the heterogeneous arrange-

ment of the particles of oxide; but on passing a current through a coil wound round the tube, these particles assume a symmetrical character, and much more light is transmitted. Tyndall (*Proc. Royal Inst.*, vol. iv. part iv. p. 231) refers the lengthening of an iron bar at the moment of magnetisation to the effort and partial success of the granules of which the bar is composed to set their longest dimensions parallel to the axis of the bar, in the same manner as iron filings, which are virtually so many little rods of iron, when shaken over a paper screen placed over a large flat magnet, set their longest dimensions in the direction of the magnetic curve.

(163) **Electro-magnetic Engines.** — The prodigious force which electro-magnets manifest when excited even by feeble currents, and the power of annulling or reversing it in an instant, might seem to justify a hope of their affording a motive power as energetic and more economical than even steam. An immense amount of inventive talent has been expended in attempts to realise this hope. These attempts have, however, shown, as Dr. Robinson observes, that electro-magnetic engines can scarcely ever be a cheap or a very efficient source of power. Electricity is now known to have a definite *mechanical equivalent.* The zinc and acid required to produce it are more costly than the coal, which will evolve *isodynamic* heat, and the hitherto-contrived methods of converting electro-magnetism into moving force involve much more loss than the mechanism of the steam-engine does in respect of heat. It may be added that the great magnetic force exists only in contact; on the least separation of the keeper it decreases rapidly, not merely because magnetic force follows the law of the inverse squares of the distance, but because that separation destroys in a very great degree the actual magnetism of the magnet. It must, however, be kept in mind that there are many cases where economy is of less consequence than facility of application and convenience; in such cases, therefore, the electro-magnetic engine may deserve preference. The power, moreover, may be applied without danger; the machine when not in active operation is perfectly quiescent, and it may be placed in any locality.

A series of experiments on the application of electro-magnetism as a motive force was made by Dumont (*Comp. Rendus*, Aug. 1851), and the following conclusions were deduced from them:—

1. That although the electro-magnetic force cannot be compared to the force of steam in the production of great power, either as regards the absolute amount of power produced or the expense, it may nevertheless under certain circumstances be usefully and practically applied.

2. That while in the development of great power the electro-magnetic

force is very inferior to that of steam, it becomes equal, and even superior, to it in the production of *small* forces, which may thus be subdivided, varied, and introduced into trades and occupations using but small capitals, where the absolute amount of mechanical power is of less consequence than the facility of producing it instantaneously and at will. In this point of view the electro-magnetic force assists as it were the usefulness of steam, in the place of uselessly competing with it.

3. Other things being proportional, electro-magnetic machines with direct alternating movement present a great superiority over rotating machines, since in the first there are no components lost, and with the same expense a much more considerable power is obtained than with rotating machines.

4. In machines of direct movement, the influence of the currents of induction appear less considerable than in rotating machines.

The first electro-magnetic engine which was something more than a mere model was constructed by Professor Jacobi, of St. Petersburg, in 1834. In 1838 he succeeded in propelling a boat, containing ten or twelve persons, on the river Neva. The vessel was a ten-oared shallop, equipped with paddle-wheels, to which rotatory motion was communicated by an electro-magnetic engine. The boat was 28 feet long and $7\frac{1}{2}$ feet in width, and drew $2\frac{3}{4}$ feet of water. At first there was great difficulty in managing the batteries, and the imperfect construction of the engine was a source of frequent interruption. During a voyage which lasted several days the vessel went at the rate of four miles per hour. In 1839 Jacobi tried a second experiment in the same boat. The machine, which was the same as that used on the previous occasion, and which occupied little space, was worked by a battery of 64 platinum plates, each having 36 square inches of surface, and charged, according to the plan of Grove, with nitric and sulphuric acid. The boat, with a party of fourteen persons on board, went *against* the stream at the rate of three miles per hour.

In *Silliman's Journal* (Nov. 1850) the fundamental principle of an electro-magnetic engine of considerable power is thus described by Professor Page:—

'It is well known that when a helix of suitable power is connected with the poles of a battery in action, an iron bar within it will remain held up by induced magnetism, although the helix be placed in a vertical position; and if the bar be partly drawn out of the helix by the hand, it goes back with a spring when the hand lets go its hold. This power, the action of the helix upon the metallic bar within it, is the power used. When a single coil is used, it has its points of greatest and weakest force, and in this condition is objectionable. But by making the coil to consist of a series of short independent helices, which are to be brought into action successively, the metallic rod is made to pass through the coil and back again with great rapidity and with an equable motion. In all the engines hitherto used, there is a loss of power at the instant of the change of current, owing to the production of a secondary current in the opposite direction; and to this loss is owing the fact that these engines cannot be rendered available.'

Page exhibited one of his engines, of between 4 and 5 horse power, at the Smithsonian Institute, the battery to operate which was contained within the space of 3 cubic feet. It was a reciprocating engine of 2-feet stroke; and the whole, including the battery, weighed about 1 ton. Page stated that the consumption of 3 lbs. of zinc per day would produce a 1-horse power. Joule's estimate is widely different; he calculates that in an electro-magnetic engine, constructed most favourably to prevent loss of power, the consumption of zinc per 24 hours to produce 1-horse power is in Grove's battery 45 lbs., and in Daniell's battery 75 lbs.

Electro-magnetic engines, in which much mechanical ingenuity is displayed, were invented by Fessel, Bain, Taylor, Davidson, Talbot, and others, but in none of them has the idea of an economical working source of power been realised. Davidson's engine, which is fully described in the *Practical Mechanic's and Engineer's Magazine*, Nov. 1842, was built on a large scale, and was tried by the inventor on the Edinburgh and Glasgow Railway; it weighed, with its carriage, batteries, &c., 5 tons, but when put in motion on the rails, it only travelled 4 miles an hour, thus exhibiting a power less than that of a single man.

Electro-motive power has, however, been employed very successfully by Gustave Froment, an eminent astronomical and mathematical instrument maker of Paris, for giving motion to machinery for performing delicate mechanical work, such as dividing-instruments, polishing apparatus, &c. &c. His machine is shown in Fig. 227, and is thus described (*Traité d'Electricité et de Magnétisme, par MM. Becquerel*) :—

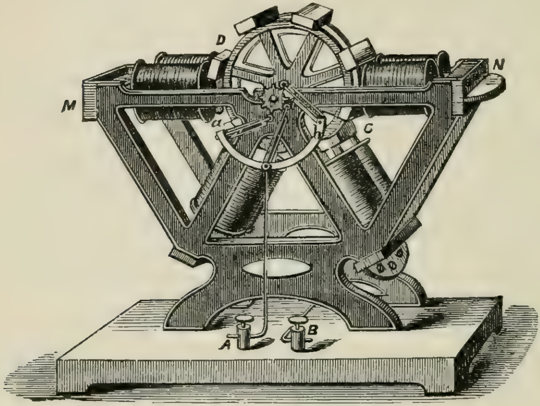
M N is a cast-iron frame supported on a base; it contains four electro-magnets, through which an electric current conveyed through the conductors attached to the binding screws A and B circulate. These electro-magnets are intended to act on the eight soft-iron armatures arranged round the circumference of the cast-iron wheel C D, which revolves on an axis. The armatures pass during rotation as near as possible the poles of the electro-magnets without actually touching. The apparatus is so arranged that each electro-magnet acts successively on each armature as it approaches near to its poles, but suspends its action when it comes immediately opposite; the next electro-magnet then comes into action, and so on; in this manner a series of impulses are given, by which continuous rotation is imparted to the wheel.

This is accomplished in the following manner :—The machine carries a distributor, which establishes and interrupts the current at a given moment, but does not change its direction. The distributor is composed of three little communicating wheels fixed on a circle, *a b*, attached to the cast-iron frame. A small cam-wheel fixed on the axis of the armature-wheel, and moving with it, raises as it revolves each of the little communicating wheels, thus producing the battery-contacts necessary for working the machine. To effect this, one of the communicators is in connection with the two lower

electro-magnets, and each of the others with one of the side electro-magnets. The circle *a b* is so arranged that the attractions take place before the armatures have arrived at the central part of each electro-magnet.

As the attractive force of the magnets is only exercised at very small distances, it is useless to allow the currents to circulate until the moment when each armature comes in close proximity to the electro-magnet—hence

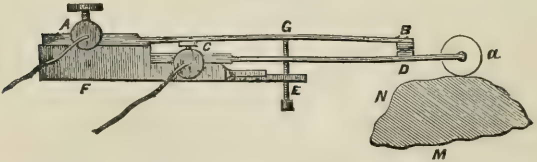
Fig. 227.



the use of so many electro-magnets, and of the division of the current during each revolution of the wheel.

The form of the communicating wheels is shown in Fig. 228. Metallic

Fig. 228.



contact between the branches A B, C D, which communicate with the poles of the battery, is prevented by the ivory plate F; the metallic plate C D carries a little ivory wheel *a*, which rolls on the wheel M, and it is only when the cam N passes over the ivory wheel that the latter establishes an electrical communication between B and D, by causing the plates of platinum with which they are furnished to come into contact. A copper screw E G, which passes through a nut E, fixed in the ivory plate F, traverses the copper plate C D through a hole without touching it, and comes into contact with G, thus regulating the duration of the contacts between B and D.

CHAPTER XIV.

DIAMAGNETISM.

Action of Magnetism on Light—Faraday's Investigations—The General Magnetic Condition of Matter—Diamagnetism of Gases—Action of Magnets on Metals—Modification of Magnetic and Diamagnetic Action by Mechanical Arrangement—Diamagnetic Polarity.

(164) **Action of Magnetism on Light.**—By the following experiment it was demonstrated by Faraday that when the 'line of magnetic force' is made to pass through certain transparent substances parallel to a ray of polarised light traversing the same body, the ray of polarised light experiences a rotation (*Phil. Trans.*, Nov. 20, 1845):—

A ray of light from an Argand lamp, polarised by reflection, was passed through a Nicol's prism revolving on a horizontal axis. Between the polarising mirror and the eyepiece, the poles of a powerful electro-magnet were arranged. The poles were separated from each other about two inches in the direction of the line of the ray, and so placed that if on the *same* side of the polarised ray it might pass near them, or if on the *contrary* side it might go between them—its direction being always parallel, or nearly so, to the magnetic lines of force. A piece of *silicated borate of lead-glass* was placed between the poles, so that the polarised ray should pass through its length. The eyepiece was now turned in such a position that the image of the ray was invisible. On causing a voltaic current to circulate the iron, *the image of the lamp-flame became visible*, and continued as long as the iron continued magnetic, but on stopping the current the light instantly disappeared.

The law of the action is this:—

If a magnetic line of force be going from a N. pole, or coming from a S. pole, along the path of a polarised ray coming to the observer, it will rotate that ray to the right hand.

Thus supposing Fig. 229 to represent a cylinder of glass, the line joining N. and S. is the magnetic line of force; and if a line be traced round the cylinder with arrow-heads on it to represent direction (as in the figure), such a simple model held up before the eye will express the whole of the law, and give every position and consequence of direction resulting from it.

Fig. 229.

The following experiment is referred to by Faraday, as clearly

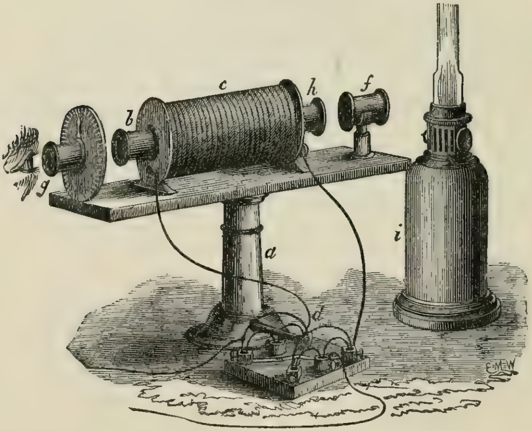
demonstrating that a ray of light may be electrified and the electric forces illuminated :—

A tube was filled with distilled water and introduced as a core into a long helix or coil ; it was placed in the line of the polarised ray, so that by examination through the eyepiece the image of the lamp-flame produced by the ray could be seen through it ; then the eyepiece was turned until the image of the flame disappeared, and afterwards a strong voltaic current was sent through the helix ; the image of the flame instantly reappeared, and continued as long as the electric current was passing through the helix ; on stopping the current the image disappeared. When the current was sent round the helix in one direction, the rotation induced upon the ray was one way ; when the current was changed, the direction of the rotation changed likewise.

The apparatus shown in Fig. 230 was constructed by Böttger for the illustration of these novel phenomena :—

a is a stand supporting a pair of achromatic Nicol's prisms, *g* and *f*, placed horizontally ; between these there is placed a brass tube, some 2 or 3

Fig. 230.



lines in diameter and from 6 to 8 inches long, closed at both ends by plates of glass, *b h* ; the tube, filled with any double reflecting liquid—such as *tartaric acid, oil of turpentine, solution of sugar*, &c.—is placed in the axis of a hollow helix, *c*, which is lined throughout its entire length with a thin cylinder of sheet-iron ; the projecting terminals of the helix are brought by means of the commutator, *d*, into connection with the poles of a Grove's battery of 6 or 7 pairs. On allowing the light from an Argand lamp, *i*, to pass through the hindermost prism, and thus causing a ray of polarised

light to traverse the solution in *h b*, it will be observed that a certain position may be given to the front movable prism, *g*, in which the field is dark; if now, by completing the circuit, the galvanic current be caused to traverse the pile in such a manner that it enters the right-handed helix where the polarised ray enters the refracting liquid, the longitudinal magnetic axis coinciding with the axis of the ray, or in other words, the magnetic N. pole being at *b*, and the S. pole at *h*, there will instantly be indicated a rotation of the plane of polarisation to the left, the field no longer remaining dark, but becoming of a reddish hue, the phenomenon remaining constant as long as the circuit is closed. On inverting the current by means of the commutator, so that the N. pole is brought to *h* and the S. pole to *b*, the plane of polarisation becomes inverted to the right, the field at the same time becoming of a bluish-green tint.

Taking the natural rotating force of a specimen of oil of turpentine as a standard of comparison, Faraday obtained the following results, a powerful electro-magnet being employed, with a constant difference of 2½ inches between the poles:—

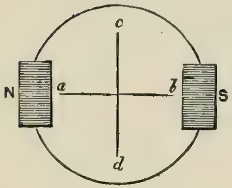
Oil of turpentine	11·8
Heavy glass	6·0
Flint-glass	2·8
Rock-salt	2·2
Water	1·0
Alcohol	less than water.
Ether	less than alcohol.

The rotatory power superinduced by magnetic action is quite independent of that which the substance possesses of itself. In oil of turpentine, for instance, whichever way a ray of polarised light passes through this fluid, it is rotated in the same manner, and rays passing in every possible direction through it *simultaneously*, are all rotated with equal force, and according to one common law of rotation—i.e. all right-handed, or else all to the left. This is not the case with the rotation superinduced on the same oil of turpentine by the magnetic or electric force; it exists only in one direction—that is, in a plane perpendicular to the magnetic line; and being limited to this plane, it can be changed in direction by a reversal of the direction of the inducing force. The direction of the rotation produced by the *natural* state is connected invariably with the direction of the ray of light, but the power to produce it appears to be possessed in every direction, and at all times, by the particles of fluid. The direction of the rotation produced by the *induced* condition is connected invariably with the direction of the *magnetic line* or the *electric current*, and the condition is possessed by the particles of matter, but strictly limited by the line or currents changing or disappearing with it.

(165) **The General Magnetic Condition of Matter.**—Previous to the communication of Faraday's memorable paper on '*New Magnetic Actions*' to the Royal Society (Dec. 1845), it was supposed that all substances might be magnetic in the sense of iron, though in so low a degree as to be inappreciable by our present means of observation. In the memoir above alluded to, however, Faraday has shown that this is by no means the case, and that there is a large class of substances which, though amenable to the influence of powerful magnets, are so in a sense absolutely the reverse of that of iron.

Thus, let N S (Fig. 231) represent the poles of a horseshoe magnet looking down upon them; the space between the poles is called the *magnetic field*; bodies magnetic in the sense of iron, if suspended in this space, take up a position with their longest diameters parallel to the line *a b*, which is called the axial line; bodies magnetic in a sense the reverse of that of iron, take up a position with their longest diameter parallel to the line *c d*, which is called the *equatorial line.*

Fig. 231.



The first substance submitted by Faraday to the action of the magnetic forces was heavy silicated borate of lead-glass. A bar of this substance, two inches wide and half an inch thick, was suspended centrally between the poles of a powerful horseshoe electro-magnet; when the effect of torsion was over, the voltaic current was thrown on, the bar immediately moved, and took up a position across the line of magnetic force (equatorial). On being displaced, it returned to it, and this happened many times in succession. The reversal of the poles of the electro-magnet caused no difference; the bar went by the shortest course to the equatorial position. Here then was a magnetic bar pointing E. and W. instead of N. and S. If the bar was suspended nearer to one pole than to the other, it was repelled from the nearer pole; and if two bars were suspended, each near the opposite pole, both were repelled by their respective poles, and thus appeared to attract each other. When a cube was employed, the effect was repulsion from both poles, and recession from the magnetic action on either side; and when one or two magnetic poles were active at once, the courses described by the glass formed a series of curves, which Faraday called *diamagnetic curves* in contradistinction to the lines called *magnetic*

curves, and the borate of lead and bodies which act like it he calls *diamagnetic* substances, in contradistinction to iron and bodies which comport themselves similar to it in the magnetic field, and which are *magnetic* substances.

Faraday submitted a great number of substances, solid and liquid, to the action of the magnet, the liquids being enclosed in small glass tubes hermetically sealed. The results are given in the following table:—

Pointed Equatorially (*Diamagnetic*).

Rock-crystal.	Nitric acid.
Sulphate of lime.	Sulphuric acid.
Sulphate of baryta.	Muriatic acid.
Sulphate of soda.	Solutions of alkaline and earthy salts.
Sulphate of magnesia.	Glass.
Alum.	Litharge.
Muriate of ammonia.	White arsenic.
Chloride of lead.	Iodine.
Chloride of sodium.	Phosphorus.
Nitrate of potassa.	Sulphur.
Carbonate of soda.	Resin.
Iceland spar.	Spermaceti.
Oxalate of lead.	Caffeine.
Tartrate of potassa and antimony.	Cinchona.
Tartaric acid.	Margaric acid.
Citric acid.	Wax from shell-lac.
Water.	Olive oil.
Alcohol.	Oil of turpentine.
Ether.	Jet.
Sugar.	Caoutchouc.
Starch.	Dried beef.
Gum-arabic.	Fresh blood.
Wood.	Leather.
Ivory.	Apple.
Dried mutton.	Bread.
Fresh beef.	

Pointed Axially (*Magnetic*).

Paper.	Sulphate of zinc.
Sealing wax.	Shell-lac.
Fluor-spar.	Silkworm gut.
Peroxide of lead.	Asbestos.
Plumbago.	Vermilion.
China ink.	Tourmaline.
Berlin porcelain.	Charcoal.
Red lead.	

Phosphorus appears to stand at the head of all diamagnetic substances; its pointing may be verified between the poles of a

common magnet. If a man could be suspended between the poles, he would point equatorially, for all the substances of which he is made possess this property.

(166) **Diamagnetism of Gases.**—It was discovered by Bancalari (Sept. 1847), that on the interposition of a flame between the poles of an electro-magnet, it was repulsed at the instant the electric current was closed, to return to its first position the instant it was broken.

On repeating this experiment with a powerful electro-magnet, Faraday observed :—1. That when the flame of a wax taper was placed so as to rise across the magnetic axis, it assumed the appearance indicated in Fig. 232, the flame being compressed

Fig. 232.

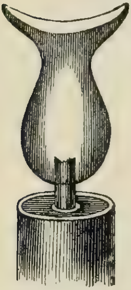


Fig. 233.

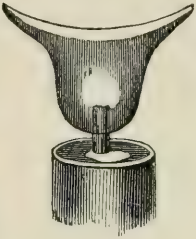
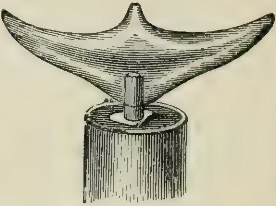


Fig. 234.



between the points of the poles. 2. That when the flame was raised it became of a fish-tail shape (Fig. 233), disposed across the magnetic axis. 3. That when the flame was raised until about two-thirds of it were above the level of the axial line, and the poles of the magnet approached within 0·3 of an inch of each other, it spread out on each side of the axial line, producing a double flame with two long tongues, as shown in Fig. 234.

By repeating and extending these experiments, Faraday was led to the discovery that common air has a decided magnetic action, and that hot air is more diamagnetic than cold air. When a current of heated air was caused to pass from an ignited platinum wire directly across the axial line, it divided into a double stream, ascending on the two sides on making the magnet active, and at the same time a descending current flowed downwards towards the hot wire. When a stream of air, artificially cooled, was directed downwards a little on one side of the axial line, it was attracted towards it—i.e. the air had by cooling been rendered magnetic in relation to air at the ordinary temperature.

Various gases, simple and compound, were examined as to their magnetic conditions by Faraday. His plan was to cause the gases to pass either upwards or downwards, according to their density, between the magnetic poles; in their passage they were made to pass over bibulous paper moistened with strong hydrochloric acid, and three *catch-tubes,* in each of which was a piece of bibulous paper, moistened with ammonia, were adjusted, one immediately over, and one on each side of, the axial line. With this arrangement it was easy to discover any effect which the magnet may exert on the gas; if no effect was produced, the gas would pass into the central tube and make itself manifest by the *white fume* of vapour of chloride of ammonium which would there be formed; but if the gas were more diamagnetic than air, it would pass into one of the side tubes, in which, and not in the central tube, the white fumes would be visible. In this way it was proved that, in relation to atmospheric air, the following gases were diamagnetic:—*Nitrogen, hydrogen* (strongly so), *carbonic acid, carbonic oxide, nitrous oxide, nitric oxide, olefiant gas, coal gas, sulphurous acid gas, muriatic acid gas, hydriodic acid gas, fluosilicon, ammonia, chlorine, iodine, bromine,* and *cyanogen.*

The most striking circumstances in these experiments were the strongly-marked diamagnetic character of *hydrogen,* and the feeble diamagnetic condition of *oxygen,* standing as it does in this respect far apart from all other gaseous substances.

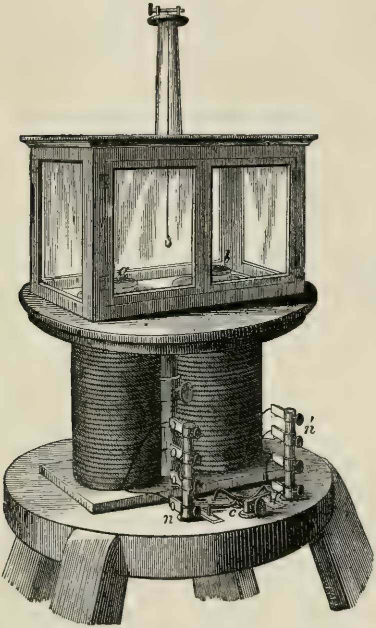
Oxygen, indeed, is a *magnetic* substance, its magnetic force being in proportion to its density. It is, in the air, what iron is in the earth, and is in striking contrast with the nitrogen which dilutes it in the atmosphere, and which is neither magnetic nor diamagnetic, but, magnetically considered, *zero.* The high magnetic condition of oxygen makes atmospheric air a magnetic medium of no small power, which must be taken into consideration when experimenting on the diamagnetic condition of other gases. The discoveries of the high magnetic condition of oxygen, and its variations with variations of temperature and density, suggested to Faraday an explanation of the cause of the variations of the magnetic force which are now so carefully watched on different parts of the surface of the globe, of the daily and annual variations of the needle, and of the relations between the aurora borealis and the magnetism of the earth. (*See* Faraday's *Exp. Researches,* series xxvi. and xxvii.; *Phil. Trans.,* Nov. 28, 1850.)

(167) **Action of the Magnet on Metals.**—For examining the action of magnetism on metals the apparatus shown in Fig. 235 was employed by Plücker. The metal was suspended by a fine filament at any required position with regard to the magnetic poles,

and surrounded with a glass case, so that the experiments could be made either in a still atmosphere, or in atmospheres more or less charged with various gases and vapours.

Of all substances hitherto tried, *bismuth* appears to be the most eminently diamagnetic, although its movements are rather complicated (from a cause subsequently traced out). It is, therefore, well suited for showing the various phenomena of diamagnetism. Each particle of the metal tends to go from the stronger to the weaker parts of the magnetic field. This is well illustrated by sprinkling some bismuth powder over a piece of paper laid over the pole of an electromagnet placed vertically. On exciting the magnet, the powder retreats in both directions, inwards and outwards, from a circular line just over the edge of the core, leaving the circle clear; and at the same time showing the tendency of the particles of bismuth to move in all directions from that line; and when the pole is terminated by a *cone*, a clear line can be traced through the powder, by drawing the paper on which the bismuth is sprinkled over the cone.

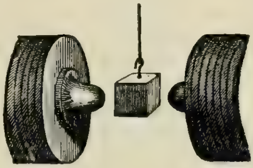
Fig. 235.



Copper and some other metals (in consequence, probably, of their excellent conducting power for electric currents) exhibit some remarkable phenomena. When a mass of copper is suspended between the poles, it first advances towards the axial line, as if it were magnetic; it then suddenly stops, and takes up a new position, from which it can only be removed by the application of some force. Even when swinging with considerable momentum it can be caught up and retained at will.

In order to form a good idea of the arresting power of those induced currents, let a lump of solid copper, approaching to the globular or cubical form, weighing from $\frac{1}{4}$ to $\frac{1}{2}$ a pound, be suspended by a long thread; let a rapid rotation be given to it, and then let it be introduced into the magnetic field of a powerful electro-magnet, as shown in Fig. 236; its motion will be instantly stopped, and on trying further to spin it whilst in the field it will be found impossible. Or let a disc of copper be set in rapid rotation and then suddenly introduced into the magnetic field, its rotation will be instantly suspended.

Fig. 236.



Faraday submitted various metallic salts to the action of the magnet. All salts and compounds containing iron in the *basic part* were found to be magnetic both in the form of crystals and when in solution: *yellow* and *red ferrocyanide of potassium* were, however, both diamagnetic; *pure sulphate and chloride of nickel*, in crystals and in solution, *oxide of chromium* and its salts, *chromic acid* and *oxide of titanium*, and the salts of *manganese* were magnetic; the salts of *lead*, *platinum*, *palladium*, and *arsenic*, on the other hand, pointing equatorially, as did also *chromate of potash*.

An interesting set of results was obtained by filling tubes with ferruginous solutions of different degrees of strength, and suspending them in similar ferruginous solutions, also of different degrees of strength, between the poles of a powerful electro-magnet. When the solution in the tube was stronger, or contained more iron, than that in the glass in which it was suspended, it pointed *axially*; when it was weaker, or contained less iron, than that in the glass, it pointed *equatorially*; and when the solutions in both tube and glass were of the same degree of strength, the tube was indifferent. *Iron* and *nickel* when heated to a degree far above that required to render them insensible to an ordinary magnet, still pointed axially between the poles.

By multiplying these experiments, the following order of metals in their relation to the magnetic force was obtained (0° is the medium point or condition of a metal or substance indifferent to the magnetic force):—

Magnetic.

Iron.	Cerium.
Nickel.	Titanium.
Cobalt.	Palladium.
Manganese.	Platinum.
Chromium.	Osmium.

Diamagnetic.

Bismuth.	Silver.
Antimony.	Copper.
Zinc.	Gold.
Tin.	Arsenic.
Cadmium.	Uranium.
Sodium.	Rhodium.
Mercury.	Iridium.
Lead.	Tungsten.

(168) **The supposed Magne-crystallic, and Optic Axis Forces.**—In his experiments on bismuth, Faraday had noticed some embarrassing results; e.g. taking at random from a quantity, four small cast cylinders of the metal, and suspending them horizontally between the magnetic poles, the first pointed *axially*, the second *equatorially*, the third *equatorial* in one position, and *obliquely equatorial* if turned round its axis 30° or 60°, the fourth *equatorially* and *axially* under the same treatment; whilst all of them were repelled by a single magnetic pole, thus showing their strong and diamagnetic character. The cause of these variations Faraday traced to the regularly crystalline condition of the metallic cylinders; the tendency of pointing being, that the line joining two opposite solid angles of the crystalline group should take up an *axial* position, and his experiments led him to the conclusion that there exists an impelling force distinct from the magnetic and the diamagnetic, and which he called the *magne-crystallic force.* The subject was minutely investigated by Plücker, who drew from his experiments the inference that there exists a relation between the *forms* of the ultimate particles of matter and the magnetic forces. According to Faraday's view, the new force discovered by Plücker is an *optic axis* force exerted in an *equatorial* direction, and therefore existing in a direction at right angles to that which produces the magne-crystallic phenomena; both forces, however, having relation to the force conferring the condition of crystalline structure, and having one common origin and cause.

(169) **Modification of Magnetic and Diamagnetic Action by Mechanical Arrangement.**—The experiments of Tyndall and Knoblauch do not confirm the law announced by Plücker, that 'there will be repulsion or attraction of the optic axis by the poles of a magnet, according to the crystalline structure of the crystal: if the crystal be a *negative* one, there will be repulsion; if a *positive*, there will be attraction.' In some cases they found this law to hold good, but in many others the results were opposed to it.

The following experiment is quoted to show that the deportment

of crystalline bodies in the magnetic field may be explained without assuming the existence of the 'optic axis' force:

'Take a slice of apple rather thicker than a penny-piece, stick through it in a direction perpendicular to its flat surface some bits of iron wire, and hang it in the magnetic field; it will set itself *equatorial*, not by *repulsion*, but by the attraction of the iron wires.

'Substitute bits of bismuth wire for the iron; the apple will now set *axial*, *not by attraction*, but by the repulsion of the bismuth.'

Now arrangement is conceivable amongst the particles of a magnetic or a diamagnetic body capable of producing similar effects; and if the magnetic and diamagnetic forces be associated with the particles of matter, the inference is not unreasonable that the *closer* these particles are aggregated, the less will be the obstruction offered to the transmission of the respective forces through them.

In another experiment, Tyndall and Knoblauch substituted for a crystal of sulphate of iron a model made of carbonate of iron, made into a paste with gum-water, and compressed and arranged so that the line of 'elective polarity' through the model was perpendicular to the length. This model, though magnetic, and strongly attracted by the magnet, actually receded from it when made to stand between the flat-faced poles *obliquely*. In the same way, by using *bismuth powder* they imitated Faraday's experiments with *crystals* of that metal. Now as by reducing the substances to powder all symmetry of crystalline arrangement is destroyed, and the force among the particles which makes them cohere in regular order rendered ineffective, it would seem that magnetism and diamagnetism are clearly modified by mechanical arrangement. The general principle is enunciated in the following law:—

'If the arrangement of the component particles of any body be such as to present different degrees of proximity in different directions, then the line of closest proximity, other circumstances being equal, will be that chosen by the respective forces for the exhibition of their greatest energy. If the mass be magnetic, this line will stand *axial*, if diamagnetic *equatorial*.'

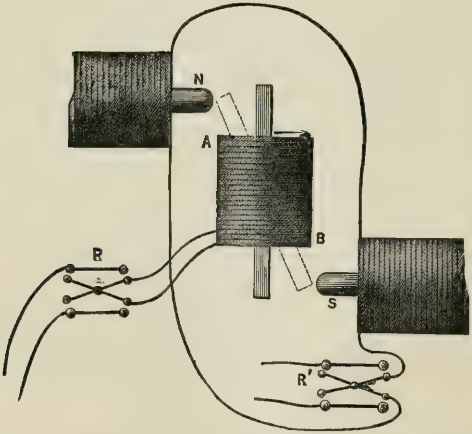
Both experiment and speculation seem indeed to concur in pronouncing the line of closest proximity among the particles to be that in which the magnetic and diamagnetic forces will exhibit themselves with peculiar energy, thus determining the position of the crystalline mass between the poles.

(170) **Diamagnetic Polarity.**—The experiments of Weber and of Faraday led them to different conclusions on this point, the former having satisfied himself that he had proved a polarity of bismuth in reverse of that of iron; and the latter stating that he

could find no evidence of diamagnetic polarity either in his own experiments or in those by Weber and Reisch. Von Feilitsch, on the other hand, endeavoured to prove (*Pogg. Ann.*) that diamagnetic bodies possess a polarity the *same* as that of iron.

In this uncertain state of the subject, the investigation was taken up by Tyndall (*Report of the British Association*, 1854; *Bakerian Lecture*, 1855; *Phil. Trans.*, 1856). For examining the question of the polarity of diamagnetic bodies, the plan first adopted was to cause fixed magnets to act upon a movable bar of bismuth encircled by an electric current, and to note, from the deflections of the bar, the character of the force acting upon it. The bar was suspended with great delicacy in the axis of a helix of covered copper wire. Opposite to either end of the bar was placed an electro-magnetic spiral, enclosing a core of soft iron. The spirals were so connected together that the same current excited both, so that the same magnetic strength was developed in both poles; and by means of a reverser the polarity of the core could be changed at pleasure. A current reverser was also attached to the helix enclosing the bismuth bar, so that the current from the battery could be caused to flow through it in either direction. The arrangement is shown in Fig. 237.

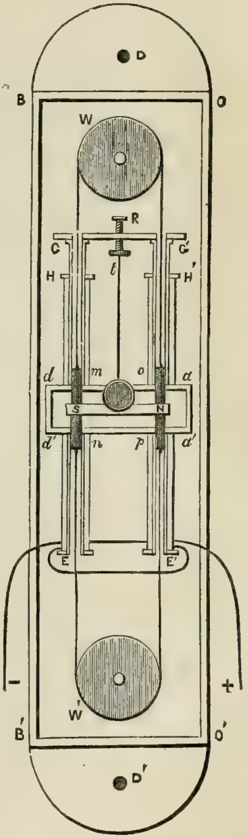
Fig. 237.



A B the helix enclosing the bismuth bar; N S the ends of the cores of the electro-magnets; R′ the current reverser of the spirals; R the current reverser of the helix.

On sending the current through the helix in the direction indicated by the arrow, the magnets being so excited that the N pole was north and the S pole south, the bar moved from its position and came to rest in the dotted position, being manifestly *attracted* by the magnets. On reversing the poles of the magnets the bismuth bar instantly loosed from the position it previously occupied, and receded from the poles: it was now *repelled*. On changing the direction of the current through the helix, attraction was again manifested. 'In all cases where the bar was freely moving in any direction under the operation of forces acting upon it, the reversion either of the current at the helix or the polarity of the cores arrested the motion; approach was converted into recession, and recession into approach.'

Fig. 238.



Tyndall subsequently investigated this subject with an apparatus based on different principles, and constructed (from a plan furnished by Weber) by Leyser, of Leipsic. The diamagnetic bar, suitably excited, is permitted to act upon an astatic system of steel magnets, and from the deflections of the system the polarity of the bar is inferred.

The apparatus, and the working of its various parts, will be understood by reference to Fig. 238. B O, B′ O′ is the outline of the rectangular case, the front of which is removed to show the apparatus within; D D′ are the screw-holes by which the box is firmly fixed to the wall; H E, H′ E′ are two copper wire helices wound round two brass reels, the upper ends of which protrude from H to G and from H′ to G′; W W′ are grooved wheels, to the string of which are attached the cylinders *m*, *n*, *o*, *p* of the body to be examined; G G is a cross-bar of brass, through the centre of which the screw R passes

from which the astatic system of magnets S N is suspended by silk fibres; the black circle in front of the magnet S N is a mirror, and the rectangle *d a*, *d′ a′* is the outline of a copper damper, which owing to the currents induced in it by the motion of the magnets, soon brings the latter to rest, and thus expedites the experiment.

The following are the details of an experiment:—

The bismuth cylinders were 3 inches long and 0·7 of an inch in diameter, and were chemically pure. A current from a single cell of Grove's battery being caused to circulate in the helices, the cylinders remaining in their centres, as in the figure, the cross wire of the telescope cut the number 650 in the scale. Turning the wheel W′ so as to raise the cylinder *m n*, and depress the cylinder *o p*, the magnet promptly moved, and after some oscillations took up a new position of equilibrium, the cross wire of the telescope then cutting 670 on the scale. Reversing the motion so as to place the cylinders again central, the former position, 650°, was assumed; on turning further in the same direction, so as to depress *m n* and raise *o p*, the position of equilibrium of the magnet was at the number 630°.

Hence by bringing the two ends *n* and *o* to bear upon the astatic magnet the motion was from smaller to greater numbers, the position of rest being then 20° greater than when the bars were central. By bringing the ends *m* and *n* to bear upon the magnet, the motion was from greater to smaller numbers, the position of rest being 20° less than when the bars were central.

When the current was caused to flow through the helices in the contrary direction, an opposite result was obtained. Thus—

The bismuth cylinders being in the centres of the helices, the cross wire of the telescope cut the number 482 on the scale. Turning the wheel so as to raise *m n* and depress *o p*, the cross wire cut 468; reversing the motion so as to place the cylinder again central, the former position of 482 was assumed, and on turning further in the same direction, so as to depress *m n* and raise *o p*, the number became 493. In this case, therefore, the first motion was from greater to smaller numbers, and the last from smaller to greater.

Cylinders of copper, antimony, heavy glass, marble, and many other substances, were submitted to experiment with this apparatus, and with all marked deflections were produced. Liquids, both magnetic and diamagnetic, were included by Tyndall in this examination, and the polarity of both was established.

CHAPTER XV.

MAGNETO-ELECTRICITY.

Induction by Voltaic Currents—Magneto-electric Induction—Terrestrial Magneto-electric Induction—Development of Magnetism by Rotation—Faraday's Researches—The Magneto-electric Machine—Applications of Magneto-electricity—Dynamo-electric Machines—Application to the Explosion of Mines and Submarine Charges—Abel's and other Fuses—Theory of the Magneto-electric Machine—Extra, Secondary, and other Currents—Induction Coil and Inductorium—Phenomena of the Induced Current—Stratification.

(171) **Induction by Voltaic Currents.**—When a current from a battery is sent through a metallic wire, it induces a wave of electricity in a second wire, forming a complete circuit, and placed parallel to it, both at the moment when contact with the battery is made and when it is broken; but while the electricity *continues* to flow through the first or *inducing* wire, no inductive effect on the second wire can be perceived.

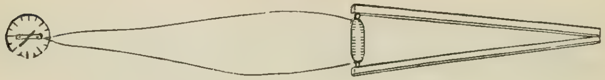
The direction of the induced wave produced on breaking battery contact, is the *reverse* of that produced on making contact; in the former case it is in the *same* direction as the battery current, in the latter case it is in the *opposite* direction.

Let a considerable length of silk-covered copper wire be wound round a block of wood; and let a second similar length of wire be arranged as a spiral between the coils of the first; let the ends of this second coil be connected with a small helix of fine-covered copper wire surrounding a small glass tube, in the axis of which is placed a common sewing-needle. On causing the current from a simple voltaic circle to pass through the first coil, and removing the needle from the helix *before* breaking contact with the battery, it will be found to be magnetised. Let a second needle be introduced into the helix, and let battery contact be then broken, this needle will also be found to be a magnet, but with its poles in a contrary direction to those of the first needle. Let the needle remain in the helix during the time of making and breaking battery contact, it will be found to have acquired very feeble magnetic properties.

(172) **Magneto-electric Induction.**—Similar waves of electricity are induced in wires by ordinary magnets without the intervention of any voltaic arrangement. Thus, if a considerable length of covered copper wire be wound round a pasteboard cylinder, containing in its axis a bar of soft iron, and its ends connected with a galvanometer, the needle of the latter will be affected in one direction on bringing the opposite poles of two strong bar

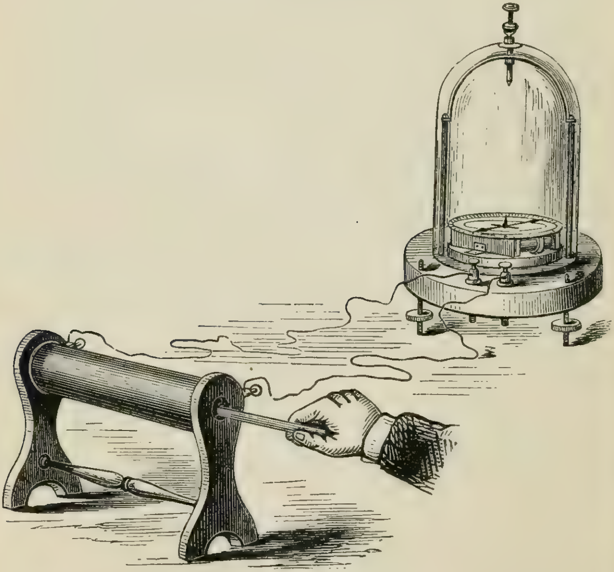
magnets into contact with the ends of the iron bar in the manner shown in Fig. 239, and in the reverse direction on removing the magnets. Or, rejecting the use of soft iron, if the ends of the helix be connected with a galvanometer, and either pole of a strong

Fig. 239.



bar magnet be thrust into its axis (in the manner shown in Fig. 240), the needle will be immediately deflected; it will soon, however, resume its original position; on withdrawing it, a second disturbance of the needle in the opposite direction will take place.

Fig. 240.



With a very strong magnet, induced currents are evinced by the galvanometer, by bringing the magnet near but not touching the end of the helix.

(173) **Terrestrial Magneto-electric Induction.**—When a piece of pure soft iron is held in the direction of the *dip* of the

needle, it becomes *pro tempore* a magnet, its lower end acquiring a N. polarity; if the bar be inverted, the polarity is at the same time changed. If such a bar be placed in the axis of a coil of wire, the ends of which are connected with a galvanometer, held in the line of the dip, and then suddenly inverted, the needle is deflected, proving the evolution of a current of electricity from the magnetism of the earth. With a somewhat larger coil the iron bar may be dispensed with, and by causing a plate of copper to rotate in a horizontal plane, electric phenomena may be produced without any other magnet than the earth. When the plate revolves in the *same* direction as the hands of a watch, the current of electricity is from the centre to the circumference; when in the *contrary* direction, the current is from the circumference to the centre. In fact, it has been shown by Faraday that it is a consequence of the universality of the magnetic influence of the earth, that scarcely any piece of metal can be moved in contact with others, either at rest or in motion, with different velocities, or in varying directions, without an electric current existing within them. In the building of one of our men-of-war, made of iron plate, it was found that there was no regularity in her compasses, and in no case were they reliable without the greatest external correction ever given. On investigating the circumstances it was noticed that the ship had been built in a N. and S. position. The iron hull had therefore obtained the characteristics of a magnet, which became intensified by the constant hammering of the plate, extending over a period of many months.

(174) **Development of Magnetism by Rotation.**—In the year 1824 Arago conceived the idea of studying the oscillations of a magnetic needle when placed above or near any body whatever. Having suspended a magnetic needle above a metal, or even water, and caused it to deviate a certain number of degrees from its normal position, it began, when left to itself, to oscillate in arcs of less and less amplitude, as if it had been placed in a resisting medium; and it was further noticed that the diminution in the amplitude of the oscillations did not alter the number that were performed in a given time.

It next occurred to Arago to try whether the needle would be dragged along by rotating the plates which had the power of diminishing the amplitude of its oscillations. This conjecture was confirmed by experiment, for on causing discs of various metals to revolve with different velocities underneath a needle suspended by a fibre of silk, a sheet of paper intervening between the needle and the disc, the needle was drawn out of the magnetic meridian the instant the disc began to revolve, with a degree of

force proportional to the velocity of the rotation; and when this was very rapid, the magnetism of the earth was overpowered, and the needle continued to turn, following the motion of the disc. On reversing the direction of the rotation of the disc, the needle gradually returned to its normal position, and then commenced rotating in the contrary direction. It was further noticed by Arago, that when the plates had portions cut out in the direction of the radii, their action on the needle was diminished.

When a circular disc of copper was suspended above a strong horseshoe magnet, placed vertically, with its poles uppermost, and made to revolve rapidly round its axis of symmetry, Babbage and Herschel found that the plate began to turn in the same direction, at first slowly, but afterwards with an increased velocity. When the magnet was made to turn in an opposite direction, the disc of copper changed the direction of its motion also. Plates of various metals, or of glass, interposed between the magnet and the disc, did not sensibly modify the results, but a sheet of tissue iron greatly diminished the influence of the magnet, while two such plates almost destroyed it. Babbage and Herschel also found that the number of revolutions performed by the disc in a given time was greatly affected by cutting the plate through in the direction of the radii, the accelerating forces diminishing with the number of solutions of continuity in the disc.

Harris found, contrary to the observations of Babbage and Herschel, that large masses of copper, silver, and zinc sensibly diminished, and, after a time, arrested altogether the motion of the revolving disc.

(175) **Faraday's Explanation of Arago's Rotations.**—All these effects have received a satisfactory explanation from the discoveries of Faraday. He has shown that when a piece of metal or conducting matter is moved across the lines of magnetic force,[1] it has, or tends to have, a current of electricity produced in it:—

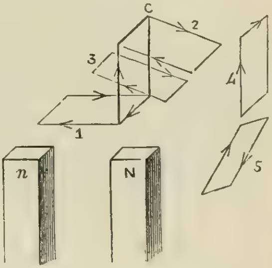
Thus, if N (Fig. 241) represent a magnetic pole, and over it a circuit be formed of metal of any shape, and which at first is in position *c*; then if that circuit be moved in one direction into position 1, or in the contrary directions into positions 2 or 3, or 4 or 5; or if the first position, *c*, be re-

---

[1] Faraday's definition of a line of magnetic force is 'that line which a very small needle describes, when it is so moved in any direction correspondent to its length, that the needle is constantly a tangent to the line of motion: or that line along which if a transverse wire be moved in either direction, there is no tendency to the formation of any current in the wire, whilst if moved in any other direction, there is such a tendency. The direction of these lines about and between ordinary magnets is easily represented in a general manner by the use of iron filings' (*Phil. Trans.* 1852).

tained, and the pole move to or towards the position *n*, then an electric current will be produced in the circuit having in every case the *same* direction, being that marked by the arrows. Reverse motions give currents in the reverse direction.

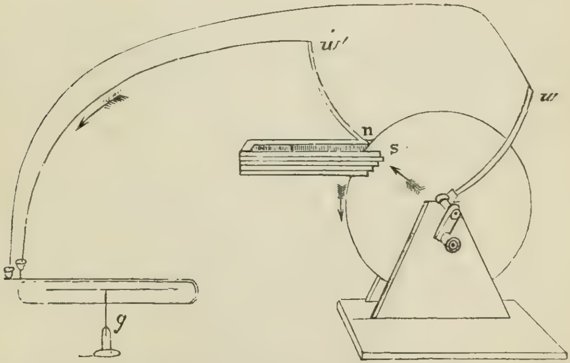
Fig. 241.



Let a copper disc (Fig. 242) be mounted on an axis, and furnished with a handle for giving it motion; let *w w'* be two copper wires, the one retained in perfect metallic contact with the axis, and the other with the circumference of the disc. Let a powerful horseshoe magnet be placed so as to allow of the revolution of the disc between its poles, and let the wires be connected with a galvanometer, *g*; the wire *w'* is retained on the circumference of the disc at the point between the poles of the magnet.

When this machine is made to revolve from right to left, a current of electricity is determined from the centre to the circumference, in the direction

Fig. 242.

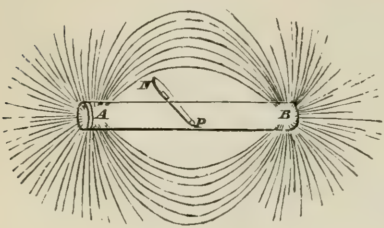


of the arrows, and the needle is deflected accordingly. If the revolution of the disc, or the poles of the magnet, be reversed, the electric current moves in an opposite direction; when the plate is at rest, there is no disturbance of the needle of the galvanometer.

The direction of the current of electricity which is excited in a metal when moving in the neighbourhood of a magnet, depends upon its relation to the magnetic curves. The following popular expression of it is given by Faraday:—

Let A B (Fig. 243) represent a cylinder magnet, A being the marked and B the unmarked pole; let P N be a silver knife-blade, resting across the magnet with its edge upward, and with its marked or notched side towards the pole A; then in whatever direction or position this knife be moved edge foremost, either about the marked or unmarked pole, the current of electricity produced will be from P to N, provided the intersecting curves proceeding from A abut upon the notched surface of the knife, and those from B upon the unnotched side; or if the knife be moved with its back foremost, the current will be from N to P in every possible position and direction, provided the intersected curves abut on the same surface as before. A little model is easily constructed by using a cylinder of wood for a magnet, a flat piece for the blade, and a piece of thread connecting one end of the cylinder with the other, and passing through a hole in the blade, for the magnetic curves; this readily gives the result in every possible direction.

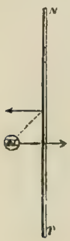
Fig. 243.



Whenever, therefore, a metallic plate is caused to revolve in the neighbourhood of a magnet, or *vice versâ*, electrical currents are determined from the centre to the circumference, or from the circumference to the centre, in the direction of the radii; and the effect is precisely the same as in electro-magnetic rotations, and is governed by the following law:—

If a wire, P N (Fig. 244), be connected with the positive and negative ends of a voltaic battery, so that the positive electricity shall pass from P to N, and a marked magnetic pole, N, be placed near the wire, between it and the spectator, the pole will move in a direction tangential to the wire, that is towards the right, and the wire will move tangentially towards the left, according to the direction of the arrows.

Fig. 244.

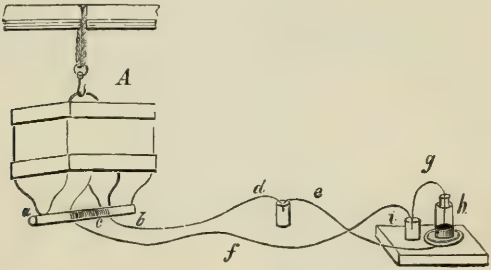


So also when a plate of metal is made to rotate beneath a magnetic pole (suppose a N pole), a series of currents of electricity will pass from the centre to the circumference of the plate if it is rotating in the direction of the hands of a watch, or from the circumference to the centre if it is rotating in the contrary direction; and it is at once evident, according to the above law, that both magnet and plate must move in the same direction; it is also evident why the phenomena cease when the magnet and metal are brought to rest, for then the electrical currents cease. The effects of a solution of the continuity of the disc in the experiments of Babbage and Herschel are likewise readily explained.

(176) **Electric Spark from the Magnet.**—(*a*) *From a Natural Magnet.*—This was first obtained in this country from a natural magnet by Professor Forbes, of Edinburgh (March 30, 1832), but it appears that the first document giving an account of the excitation of a spark from a permanent magnet is by Signor Nobili, and another dated from the museum at Florence, Jan. 31, 1832. The experiment of Forbes was arranged as shown in Fig. 245 :—

A is a powerful natural magnet or loadstone capable of supporting 170 lbs.; *a b* a cylindrical collector of soft iron passing through the axis of the helix *c*, and connecting the poles of the magnet. Accuracy of contact was found to be of considerable importance to the success of the experiment, and one side of the cylinder was carefully formed to a curve of about 2 inches radius for this purpose. Great advantage was found from the use of a mechanical

Fig. 245



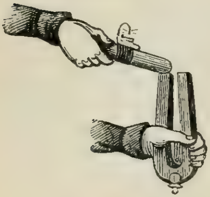
guide, not represented in the figure, to enable an assistant to bring up the connector rapidly and accurately to the magnet in the dark.

The helix *c* consisted of about 150 feet of copper wire, about $\frac{1}{20}$ of an inch in diameter, was $7\frac{1}{2}$ inches long, and was arranged in 4 layers, which were carefully separated by insulating partitions of cloth and sealing wax. The one termination, *d e*, of the wire passed into the bottom of the glass tube *h*, half-filled with mercury, in which the wire terminated, and the purity of the mercurial surface was found to be of great consequence. The other extremity, *f*, of the heliacal wire communicated by means of the cup of mercury *i* with the iron wire *g*, the fine point of which may be brought by the hand into contact with the surface of mercury in *h*, and separated from it at the instant when the contact of the connector *a b* with the poles of the magnet is effected. The spark is produced in the tube *h*.

The success of this experiment obviously depends on the synchronism of the production of the momentary current by connecting the magnetic poles and the interruption of the circuit at the surface of the mercury; with a little practice, Forbes was able to produce, for many times in succession, at least two sparks from every three successive contacts.

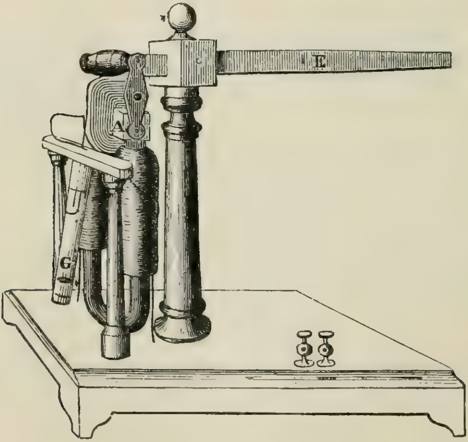
(*b*) *From an Artificial Magnet.*—The magnetic spark may be produced with great ease and certainty from an artificial magnet of moderate strength, by employing the little arrangement shown in Fig. 246. It consists merely of a cylinder of soft iron, round the centre of which is wound a few feet of insulated copper wire; to one end of this wire is soldered a small disc of copper, which is well amalgamated; the other end is bent up, the point cleaned and amalgamated, and brought into contact with the disc. On laying this cylinder across the poles of the magnet, and then suddenly breaking contact, the point and the disc become separated at the same time, and the spark appears.

Fig. 246.



(*c*) *From an Electro-magnet.*—Round the soft iron lifter of a horseshoe electro-magnet capable of carrying from 15 lbs. to 20 lbs., ten or twelve feet of insulated copper wire are wound. To the ends of

Fig. 247.



the coil two thick copper wires are to be soldered, in order to form a complete metallic circuit when the lifter is in contact with the poles of the magnet. The magnet is mounted poles upward on a wooden stand, having a pillar with an arm or lever passing through

a mortice in the top of it, for the purpose of removing by a sudden jerk the lifter from the poles of the magnet.

In front of the magnet a glass tube is fixed, having its top closed by a cap of boxwood, through which the copper wires soldered to the extremities of the coil pass as near air-tight as possible into the glass tube; the end of one wire, being flattened, is bent at right angles and well amalgamated. The other, which is straight, can be brought down or removed from it by means of the lever. The whole arrangement will be readily understood by an inspection of Fig. 247.

The mixed gases are introduced into the tube G by means of a bent or flexible tube. On giving the lever E a smart blow with the palm of the hand the iron lifter A B is suddenly removed from the poles of the magnet, a current of electricity is induced in the coil, contact between the wires in the tube G is broken, a spark appears, and the gases are immediately exploded.

(177) **The Magneto-electric Machine.**—The first instrument by which a rapid succession of sparks could be obtained from a permanent magnet was invented by Hippolyte Pixii, of Paris, and was first made public at the meeting of the Academy of Sciences, on Sept. 3, 1832. In June 1833 Mr. Saxton exhibited his improvement on Pixii's machine, and in 1835 he added to the machine the double armature, with which he could produce, at pleasure, brilliant sparks and strong heating power, or violent shocks and chemical decomposition.

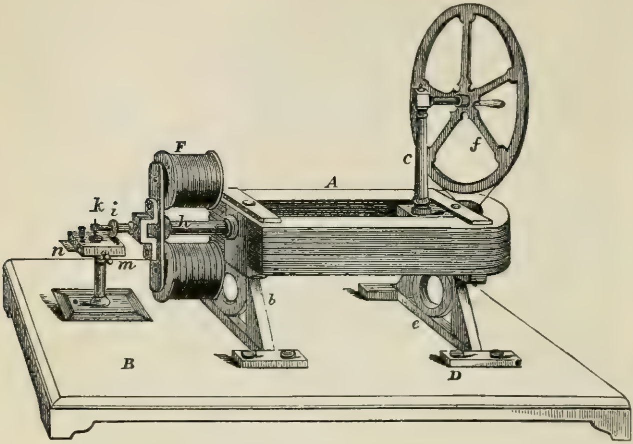
Saxton's machine, as lately constructed, is shown in Fig. 248. Figs. 249, 250, 251, 252, 253, 254, show the different arrangements, and their application to illustrate various electrical phenomena. The letters in Fig. 248 answer to the same in the other figures:—

A is a compound horseshoe magnet, composed of six or more bars, and supported on the rests *b e*, which are screwed firmly on the board B D; into the rest *e* is screwed the brass pillar *c*, carrying the wheel *f*, having a groove in its circumference, and a handle by which it can be readily revolved on its axis. A spindle passes from one end of the magnet to the other, between the poles, and projects beyond them about three inches, where it terminates in a screw at *k*, to which the armatures, to be described immediately, are attached; at the farther extremity is a small pulley, over which a gut band passes, by means of which, and the multiplying wheel *f*, the armatures can be revolved with great rapidity.

The armatures or *inductors*, as seen at F, are nothing more than electro-magnets. Two pieces of round iron are attached to a cross piece, into the centre of which the spindle *h* screws. Round each of these bars is wound in a continuous circuit a quantity of insulated copper wire, one end being soldered to the disc *i*, the other connected with the copper wire passing through, but insulated from it by an ivory ring. By means of the wheel and spindle each pole of the armature is brought in rapid succession opposite

each pole of the magnet, and that as near as possible without absolutely touching. The two armatures differ from one another. The one termed

Fig. 248.



the *quantity* armature is constructed of stout iron, and covered with thick insulated wire. The other, termed the *intensity* armature, is constructed of

Fig. 249.

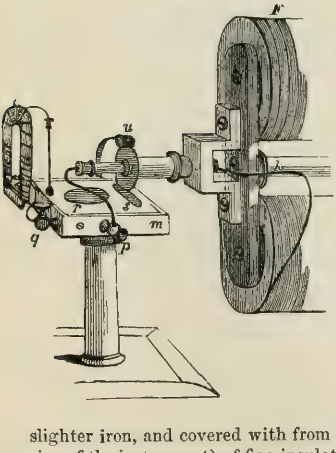
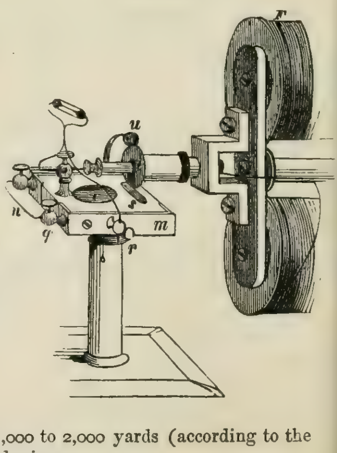


Fig. 250.



slighter iron, and covered with from 1,000 to 2,000 yards (according to the size of the instrument) of fine insulated wire.

The *quantity* armature is adapted for exhibiting the spark (Fig. 248), inducing magnetism in soft iron (Fig. 249), heating platinum wire (Fig. 250), igniting charcoal points (Fig. 251), scintillating steel on a file (Fig. 252), &c.

Fig. 251.

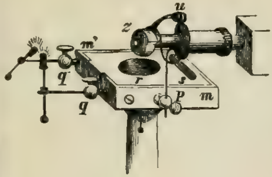


Fig. 253.

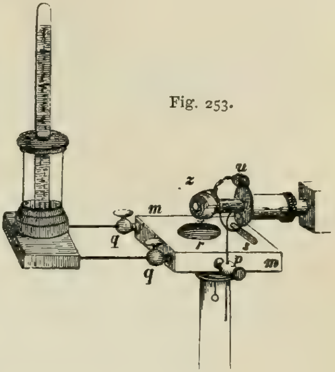
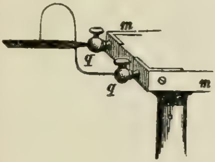


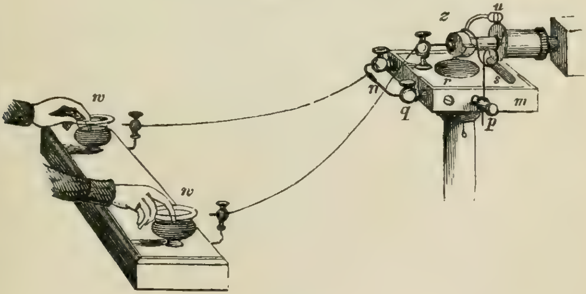
Fig. 252.



The intensity armature is best adapted for administering the shock (Fig. 254), and for effecting chemical decomposition (Fig. 253).

The *flood-cup* is that part of the instrument to which the different apparatus used to illustrate the various phenomena are attached. The one here

Fig. 254.



represented can be used either with or without mercury. It consists of a square block of wood supported on a stand, capable of being raised or lowered to the height required. Two hollows, *r* and *s*, are made on the top, into which mercury is put when that medium is required, the round metal disc *i* (Fig. 248) revolves in *s*, and the point *k* just dips into *r*; the wire fork *n*

connects the two floods of mercury together. On revolving the armature, contact is continually broken and renewed at the point *k*, and a succession of sparks forming almost continuous light is produced. Two pieces of stout brass, *m*, bent at two right angles, are fixed to the sides of the wood block, but insulated from each other; to these are attached binding screws, which answer in every respect the same purpose as mercury.

(178) **Application of Magneto-electricity to the Production of Light.**—This is due to Mr. Holmes, who exhibited an effective arrangement for the purpose in the International Exhibition of 1862, which is thus described in the *Jurors' Report*:—

'The currents are induced by the rapid passage of coils of copper wire wound round soft iron cores, between the poles of powerful horseshoe magnets. The alternately inverted currents produced in this manner are transmitted by means of a commutator in one direction only, through the carbon electrodes of an electric lamp somewhat similar in principle to that of Duboscq (131). There are eighty-eight coils arranged on two parallel rings, each containing forty-four equally-spaced bobbins; the rings are fixed in the rim of a large wheel, about five feet in diameter, the axes of the coils being parallel to the axis of the wheel. The wheel is driven at about 110 revolutions per minute. The horseshoe magnets are fixed on a frame round the circumference of the wheel in three planes or rings of twenty-two each. The two poles of each magnet are in one and the same plane or ring. The distance between their poles is equal to the distance between the bobbins or coils. The magnets in the two outside rings have similar poles opposite one another. The magnets of the inner ring are placed with opposite poles facing the similar poles of the outer rings. The two outside rings have compound magnets of four plates; the magnets of the inner ring, between the two sets of bobbins, have six plates. The weight of each plate is six pounds. The distance between the successive magnets corresponds to the distance between the centres of the coils, so that each alternate coil has a core magnetised in the opposite direction, but the wires are so connected that the currents flow in the same direction. The length of the hollow iron core inside each bobbin is $3\frac{1}{2}$ inches; itsexternal diameter $1\frac{1}{2}$ inch; its internal diameter 1 inch; two copper wires 0·148 inch diameter, forty-five feet long, are wound round each core, and connected in double arc; these wires are equivalent to one wire 0·2 inch diameter of the same length. The core and brass bobbin are split to prevent useless currents outside the coils.

'As the wheel revolves, each core continually changes its polarity as it passes between the alternating poles of successive pairs of magnets. This change of polarity occurs forty-four times for each

coil of each ring; the change is simultaneous for all the coils in one ring, but the moment of maximum change of one ring corresponds to the moment of minimum change in the other. All the coils of each ring are connected in series, and it will be seen from the above description, that each ring will induce forty-four distinct currents, each due to forty-four coils during each revolution of the wheel. The coils of both rings are connected with an ingenious commutator, by which they are so combined that the induced currents shall continually pass in the same direction through the carbon electrodes of the lamp, although passing in four distinct successive combinations through the coils.

'As already stated, the maximum current from one ring corresponds with the minimum current from the other, and as each current lasts a very sensible time, during which it gradually rises and falls, their combination does not simply produce twice the number of sparks that would be obtained from one ring of coils, but a nearly constant and uniform current, in which the fall of the current from one series of coils is almost exactly compensated by the rise of the current from the other. As each revolution induces eighty-eight distinct currents, the machine, when driven at the speed mentioned, sends 9,680 currents through the carbon electrodes of the lamp every minute.'

Holmes's magneto-electric machine and lamp have been in successful operation at Dungeness Lighthouse since June 1862, exclusively in the hands, and under the care of, the Trinity House. This machine has been subsequently removed, and a larger machine was erected in 1872 at the South Foreland, illuminating both of the lighthouses situated there.

The visible conversion of mechanical work into heat and light, by the agency of electricity in this machine, gives an interesting example of the transformation of energy. The excess of power required to drive the machine when the electric currents are closed, is stated to be very sensible. One-and-a-quarter horse power is required to drive the machine when the light is in action.

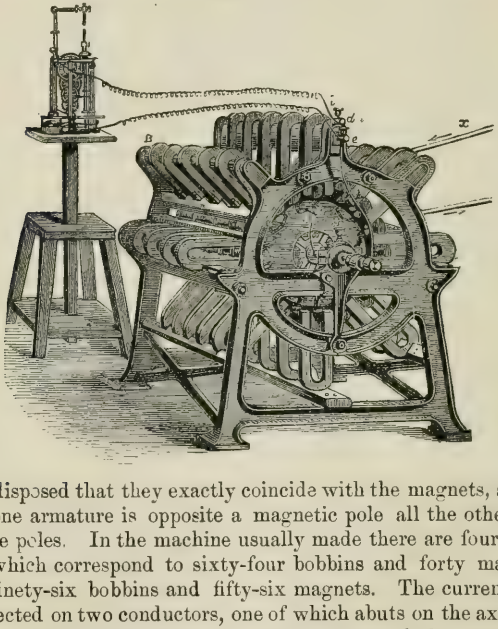
The application of the magneto-electric machine to electroplating has already been alluded to (125). A machine originally intended for the production of illuminating gas by the decomposition of water, was shown at the International Exhibition of 1862, by Shepard. The arrangement of magnets and coils is very similar to that of Holmes, but it could not be worked at a profit as a gas generator.

(179) **Société l'Alliance Magneto-electric Machine.**—This machine (Fig. 255), which is exclusively used in France for electric

light purposes on shore as well as on board vessels, was originally the invention of M. Nollet, professor of physics at the Military School, Brussels, and has been greatly improved and brought to its present state by M. van Malderen.

It is made in two or three sizes, and consists of a certain number of brass discs C, each carrying at its circumference sixteen bobbin armatures. The discs are keyed on a shaft, driven by a steam engine by means of the belt *x*, and they revolve between eight sets of magnets B. As each magnet has two poles, each series has sixteen poles, equally spaced in a circle. The armatures

Fig. 255.



are so disposed that they exactly coincide with the magnets, so that when one armature is opposite a magnetic pole all the others are opposite poles. In the machine usually made there are four or six discs, which correspond to sixty-four bobbins and forty magnets, or to ninety-six bobbins and fifty-six magnets. The currents are all collected on two conductors, one of which abuts on the axis, and is thence put in communication with the rest of the apparatus. The other conductor terminates in an insulated sleeve concentric with the main axis. The wires are fixed by binding screws *d e* to these conductors, as shown. The current changes its direction each time that a bobbin passes a pole. There are sixteen changes for each disc, and inasmuch as the machine makes 400 revolutions per minute, there are 6,400 changes in a minute, or over 100 per

second. No commutator is used, as it has been found that it is possible to produce the electric light with currents which do not flow always in the same direction. It will be understood that when currents are reversed there must be at each reversal a zero or period when no current is passing; at this moment the electric light is extinguished, but the fact will be imperceptible to the senses provided the light is not extinguished for more than the hundredth part of a second, because the impression of the light remains on the retina. It is considered that the balance of advantage lies with the machines fitted with commutators.

(180) **A new and Powerful Generator of Dynamic Electricity.**—A paper was communicated to the Royal Society, by H. Wilde (*Proc. Royal Society*, No. 83, vol. xv., March 26, 1866), in which attention was drawn to some new and paradoxical phenomena arising out of Faraday's important discovery of magneto-electric induction (172), the close consideration of which has resulted in the discovery of a means of producing dynamic electricity in quantities unattainable by any other apparatus hitherto constructed; an indefinitely small amount of magnetism, or of dynamic electricity, having been found capable of inducing an indefinitely large amount of magnetism—and again, an indefinitely small amount of dynamic electricity, or of magnetism, being capable of evolving an indefinitely large amount of dynamic electricity.

The apparatus with which the experiments were made was thus described:—

> A compound hollow cylinder of brass and iron was constructed, termed by the author a magnet cylinder, its internal diameter being 1⅝ inch. On this cylinder could be placed, at pleasure, one or more permanent horseshoe magnets. Each of these permanent magnets weighed about 1 lb., and would sustain a weight of about 10 lbs. An armature was made to revolve rapidly in the interior of the cylinder, in close proximity to its sides, but not touching. Around this armature 183 feet of insulated copper wire, 0·03 of an inch in diameter, were coiled, and the free ends of the wire were connected with a communicator fixed upon the armature axis for the purpose of taking the alternating waves of electricity from the machine in one direction only. The direct current of electricity was then transmitted through the coils of a tangent galvanometer; and as each additional magnet was placed upon the magnet-cylinder, it was found that the quantity of electricity generated in the coils of the armature was very nearly in direct proportion to the number of magnets on the cylinder.

Experiments were next made for the purpose of ascertaining what relation existed between the sustaining power of the permanent magnets on the magnet-cylinder, and that of an electro-magnet excited by the electricity derived from the armature; and

it was found that when four permanent magnets, capable of sustaining collectively a weight of 40 lbs., were placed upon the cylinder, and when the sub-magnet was placed in contact with the poles of the electro-magnet, a weight of 178 lbs. was required to separate them. With a larger electro-magnet, a weight of not less than 1,080 lbs. was required to overcome the attractive force of the electro-magnet, or twenty-seven times the weight, which the four permanent magnets, used in exciting it, were collectively able to sustain. It was further found that this great difference between the power of a permanent magnet and that of an electro-magnet excited through its agency might be indefinitely increased.

An electro-magnet would appear, from the experiments of Wilde, to possess the power of accumulating and retaining a charge of electricity in a manner analogous to, but not identical with, that in which it is retained in insulated submarine cables, and in the Leyden jar. Thus when the wires forming the polar terminals of the magneto-electric machine were connected for a short time with those of a very large electro-magnet, a bright spark could be obtained from the electro-helices twenty-five seconds after all connection with the magneto-electric machine had been broken. It was found also that the electro-helices offered a temporary resistance to the passage of the current from the magneto-electric machine. When four magnets were placed on the cylinder, the current from the machine did not attain a permanent degree of intensity until an interval of fifteen seconds had elapsed; but when a more powerful machine was used for exciting the electro-helices, the current attained a permanent degree of intensity after an interval of four seconds had elapsed.

The general conclusion which Wilde drew from a consideration of these remarkable experiments was, that when an electro-magnet is excited through the agency of a permanent magnet, the large amount of magnetism manifested in the electro-magnet simultaneously with the small amount manifested in the permanent magnet is the constant accompaniment of a correlative amount of electricity evolved from the magneto-electric machine, either all at once, in a large quantity, or by a continuous succession of small quantities; the power which the metals (but more particularly iron) possess of accumulating and retaining a temporary charge of electricity or magnetism, or of both together (according to the mode in which these forces are viewed by physicists), giving rise to the paradoxical phenomena which form the subject of this part of the investigation.

Having established the fact that a large amount of magnetism can be developed in an electro-magnet by means of a permanent

magnet of much smaller power, it occurred to Wilde that a large electro-magnet, excited by means of a small magneto-electric machine, might by suitable arrangements be made instrumental in evolving a proportionately large amount of dynamic electricity. In order to test this view, a machine was constructed as follows :—

Two magnet-cylinders were made having a bore of 2½ inches, and a length of 12½ inches, or five times the diameter of the bore. Each cylinder was fitted with an armature, round which was coiled an insulated strand of copper wire 67 feet in length, and 0·15 of an inch in diameter. Upon one of the magnet-cylinders sixteen permanent magnets were fixed, and to the sides of the other magnet-cylinder was bolted an electro-magnet, formed of two rectangular pieces of boiler-plate enveloped with coils of insulated copper wire. The armatures of the magneto-electric and electro-magnetic machines were driven simultaneously, at an equal velocity of 2,500 revolutions per minute. When the electricity from the magneto-electric machine was transmitted through a piece of No. 20 wire 0·04 of an inch in diameter, a length of three inches was made red hot. When the direct current from the magneto-electric machine was transmitted through the coils of the electro-magnet of the electro-magnetic machine, the electricity from the latter *melted eight inches of the same sized wire, and a length of twenty-four inches was made red hot.*

When the electro-magnet of a 5-inch machine was excited by the 2½-inch magneto-electric machine, the electricity from the 5-inch electro-magnetic machine melted fifteen inches of No. 15 iron wire 0·075 inch in diameter.

Having thus found that an increase in the dimensions of the machines was accompanied by a proportionate increase of the magnetic and electric forces, Mr. Wilde proceeded to construct a machine, the magnet-cylinder of which was 10 inches in diameter, the weight of the electro-magnet was nearly 3 tons, and the total weight of the machine about 4½ tons. The machine was furnished with two armatures, one for the production of 'intensity,' and the other for the production of 'quantity' effects.

The 'intensity' armature was coiled with an insulated conductor, consisting of a bundle of thirteen No. 11 copper wires, each 0·125 inch in diameter. The coil was 376 feet in length, and weighed 232 lbs.

The 'quantity' armature was enveloped with folds of an insulated copper-plate conductor 67 feet in length, the weight of which was 344 lbs. These armatures were driven at the uniform velocity of 1,500 revolutions per minute, by means of a broad leather belt of the strongest description.

When the direct current from the 1⅝-inch magneto-electric machine, having on its cylinder six permanent magnets, was transmitted through the coils of the electro-magnet of the 5-inch electro-magnetic machine, and when the direct current from the latter was simultaneously, and in like manner, transmitted through

the coils of the electro-magnet of the 10-inch machine, an amount of magnetic force was developed in the large electro-magnet far exceeding anything which had hitherto been produced, accompanied by the evolution of an amount of dynamic electricity from the quantity armature, so enormous as to *melt pieces of cylindrical iron* 15 *inches in length and fully* $\frac{1}{4}$ *of an inch in diameter, and* 15 *inches of copper wire* (No. 11) 0·125 *of an inch in diameter.*

When the 'intensity' armature was placed in the magnet-cylinder, the electricity from it melted 7 feet of No. 16 iron wire 0·065 of an inch in diameter, and made a length of 21 feet of the same wire red hot.

The illuminating power of the electricity from the intensity armature was of the most splendid description, as might be expected:—

'When an electric lamp, furnished with rods of gas-carbon half an inch square, was placed at the top of a lofty building, the light evolved from it was sufficient to cast the shadows from the flames of the street-lamps, a quarter of a mile distant, upon the neighbouring walls. When viewed from that distance, the rays proceeding from the reflector had all the rich effulgence of sunshine.

'A piece of the ordinary sensitised paper such as is used for photographic printing, when exposed to the action of the light for twenty seconds, at a distance of two feet from the reflector, was darkened to the same degree as was a piece of the same sheet of paper when exposed for a period of one minute to the direct rays of the sun at noon, on a very clear day in the month of March.'

The extraordinary calorific and illuminating powers of the 10-inch machines are all the more remarkable from the fact that they have their origin in six small permanent magnets, weighing only *one pound each*, and capable at most of sustaining collectively a weight of 60 lbs.; while the electricity of the magneto-electric machine employed in exciting the electro-magnet was itself incapable of heating to redness the shortest length of iron wire of the smallest size manufactured.

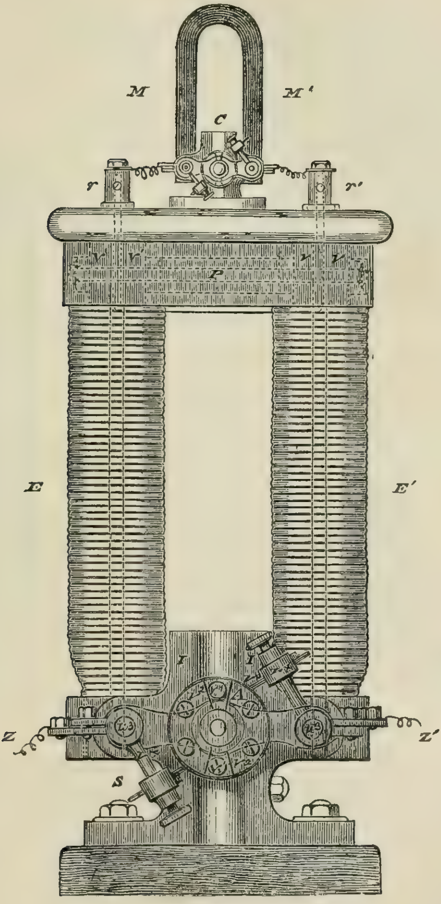
The production of so large an amount of electricity was only obtained by a correspondingly large amount of mechanical force; for it was found that the large electro-magnet could be excited to such a degree that the strong leather belt was scarcely able to drive the machine.

(181) **Wilde's Magneto-electric Machine.**—Later on Mr. H. Wilde, March 23, 1867, patented a magneto-electric machine involving improvements of the principle just described. The following is a description of the machine as patented.

The diagram (Fig. 256), shows a front elevation of the complete machine, which consists principally of a large electro-magnetic

machine E E,′ which is also magneto-electric, and of a smaller machine M M′, which is purely magnetic. The horseshoe permanent magnet M M′ is the foremost of a series of sixteen similar

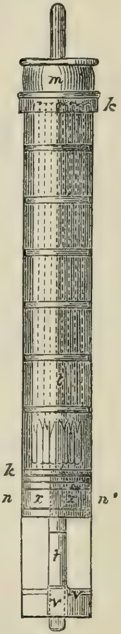
Fig. 256.



magnets, placed the one behind the other in a horizontal row. Each weighs 3 lbs., and sustains a weight of 20 lbs. The sixteen magnets are fixed below to the 'magnet-cylinder' C, shown on a

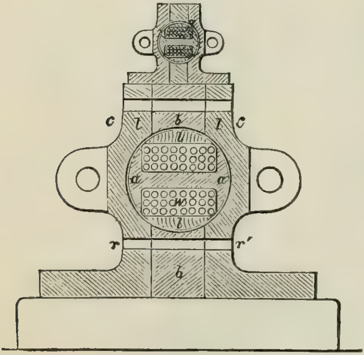
larger scale in Fig. 257. This is partly made up of cast iron, partly of brass. The two iron components (Fig. 256) form the sides of it, and the brass bars lie between them. They are bolted firmly together by the brass bolts *r r′*. The magnet-cylinder is about 12 inches in length; in the centre of it is accurately bored a circular hole, extending the whole way, $2\frac{1}{2}$ inches in diameter. The inner side surfaces of the magnets below are accurately fitted to the upright-plane sides of the magnet-cylinder, and are firmly secured to it. By this means the cast-iron portions of the magnet-cylinder *i i* form the polar terminations of the magnetic battery, the brass bars *b b* between them breaking the magnetic continuity.

Fig. 258.



A cylindrical armature *a a* of cast iron is made to revolve within the magnet-cylinder. Its diameter is $\frac{1}{20}$ of an inch less than the diameter of the cylinder, which enables it to revolve without friction in very close proximity to the polar

Fig. 257.



surfaces. The manner in which it is centred is, for the sake of simplicity, not shown in the upper machine, where, as is afterwards mentioned, the construction, though larger, is perfectly similar. The framework for sustaining the axis of the armature is firmly bolted. Fig. 257 gives, as just mentioned, an enlarged cross-section; Fig. 258 shows an enlarged side-view. Two rectangular grooves *w l* are made on opposite sides, giving to it somewhat the appearances of a rail. About 50 feet of insulated copper wire *w w* are wound lengthwise into these grooves in three coils (shown

in section, Fig. 257). The coil thus formed is shut in by wooden packing $l\,l$; in Fig. 258 this packing is removed at one end to show the longitudinal winding of the coil. To prevent the wires from being driven out by the centrifugal force generated by the rapid rotation of the armature, straps of sheet brass encircle the armature at regular intervals and are sunk in grooves prepared for them in the cast iron. Two caps of brass $k\,k$ are fitted to the side of the armature, and to these are attached the steel journals or axes of rotation. On the further axis (the back axis of Fig. 258) the pulley m is fixed, round which passes the strap from the steam engine which works the machine. On the other axis (the front axis of the figure) two rings are put, one n insulated from it and the other n' connected with it. One end of the armature coil is in connection with the armature, and thereby with the axis and n'; the other end is insulated and fixed by a binding-screw with n; n and n' are thus the terminals of the coil. They are made of hardened steel, and the springs s and s' which press against them are of the same material.

Starting from any definite position, the armature in one revolution induces two opposite currents in the coil, one in the first, the other in the second half-revolution. As n and n' change their electric sign, it is so arranged that they change the spring s or s' against which they press. Thus s and s' receive their currents always in the same direction. The armature is made to revolve 2,500 times per minute, and 5,000 waves or currents of electricity are transmitted to the wires.

Thus far we have nothing essentially peculiar in Wilde's machine. The construction of the magnet-cylinder is quite novel, though the position of the armature, which is decidedly the most advantageous, is not new, as it was adopted several years ago in Siemens and Halske's magneto-electric machine.[1] One advantage of this position lies in the motion of the armature not being resisted by the air. In the ordinary position of the armature (Fig. 248) much of the work applied to the rotation is expended in the armature beating the air. There is no such loss in Siemens and Halske's or Wilde's machine. Another advantage is derived from the inductive action of the magnet being exerted directly on the coil, as well as through the intervention of the armature. If the coil were made to rotate without the armature, currents would be induced in it of the same kind as that induced by the armature, though of feebler intensity, the maximum points of which would occur when the coil was moving through the line joining the poles, and the minimum points when it was at right angles to that

[1] It is the invention of Dr. William Siemens, of Berlin.

position. Now these are the converse of the maximum and minimum induction points of the armature. In the position in which the armature is placed in this machine, both armature and coil contribute to the current, the one most when the other gives least, and *vice versa*. The same advantage is not secured by the ordinary construction.

We now come to describe the singular peculiarity and merit of Wilde's machine. The current obtained from the magneto-electric machine is not directly made use of, but is employed to generate an electro-magnet some hundreds of times more powerful than the magnetic battery originally employed, by means of which a corresponding increase of electricity may be obtained. This electro-magnet E E′ (Fig. 256) forms the lower part of the figure, and by far the most bulky portion of the entire machine. It is of the horseshoe form, E and E′ forming the two limbs of it. The core of each of these, shown by the dotted lines, is formed by a plate of rolled iron, 36 inches in height, 26 inches in length, and 1 inch in thickness. Each is surrounded by a coil of insulated copper wire (No. 10) 1,650 feet long, wound round lengthwise in seven layers. The current has thus, in passing from the insulated binding screw *r* to the similar screw, to make a circuit of 3,300 feet. Each limb of the electro-magnet is thus a flat reel of covered wire wrapped round a sheet of iron, the rounded ends alone of which are seen in the figure. The upright iron plates are joined above by a bridge P, built up also of iron-plate, and are fixed below the whole way along with the iron bars *v v* to the sides of a magnet-cylinder of precisely the same construction as the one already described. The iron framework of the electro-magnet is shown by the dotted lines. The depth of the bridge is the same as the breadth of the bars *v′ v′*, which are of the same size as the bars *v v*. The various surfaces of juncture in the framework are placed so as to ensure perfect metallic contact. The upper and lower machine are in action precisely alike, only the upper magnet is a permanent magnet and the lower one an electro-magnet. We have the same magnet-cylinder I I, the same armature A, and springs S S, and the same poles Z Z′; the size, is, however, different, the calibre of the magnet-cylinder being 7 inches. The diameter of the lower armature gives the name to the machine—viz. a 7-inch machine. The length of wire on the lower armature is 350 feet. It is 35 inches in length, and is made to rotate 1,800 times a minute. The cross framework attached to the magnet-cylinder, in which the front journal of the armature rotates (at Q), is shown in the lower machine (Fig. 256). When the machine is in action, both armatures are driven simultaneously from the same

countershaft. For the electric light, the currents conveyed to the springs *s* and *s′* need not be sent in the same direction. In that case the separation between *s* and *s′* is vertical; and each spring presses against only one ring during the whole revolution, receiving and transmitting each revolution two opposite currents.

The machine here described is intended for a three-horse power steam-engine, but nine-power might be expended on it.

Mr. Wilde furnishes for the electro-magnet cylinder of many of his machines two armatures—one an 'intensity armature,' similar to that just described; the other a 'quantity armature'—one of which may be easily substituted for the other. The quantity armature, instead of insulated copper-wire, is enveloped in folds of insulated copper-plate, or ribbon, which offering little resistance, a current of much greater quantity, though of less tension, is given off. It is with the quantity armature that experiments in the heating power of the machine are best performed. With a 10-inch quantity armature Mr. Wilde succeeded in melting an iron rod 15 inches long and $\frac{1}{4}$ inch thick.

The entire machine just described is under 5 feet in length and height, is 20 inches wide, and weighs a ton and a half.

(*Ferguson.*)

The residual magnetism of the electro-magnetic induction machine may also be employed for exciting its own electro-magnet in the following manner:—Fig. 257 is a cross section of a machine for utilising the residual magnetism of the electro-magnet and magnet-cylinder of an electro-magnetic machine. The small armature *o* (not previously described) for exciting the electro-magnet, and the larger armature *a a* for producing the more powerful current, are made to revolve simultaneously by two magnet-cylinders *q* and *l l* placed one above the other between the two poles of the electro-magnet; these two cylinders are placed with their axes parallel to each other, and the two segmental iron sides of the small cylinder are bolted to those of the large cylinder. The iron of the two cylinders being thus in close contact, the smaller cylinder *q* acquires the same degree of residual magnetism as the large cylinder *l*, which in machines of large dimensions is very considerable. By this arrangement the large electro-magnet s, bolted to the sides of the large magnet-cylinder *l*, supplies the magnetism required to excite the armature *o* revolving in the smaller cylinder *q*, and the alternating current induced in the coils of the armature *o* by the residual magnetism of the two cylinders, after being turned in one direction by means of a commutator, is transmitted through the coils of the electro-magnet on the large cylinder in the usual manner, the magnetism of which is thereby greatly

augmented, and the more powerful current obtained from the larger armature *a a* can be made available for any purpose to which such currents of electricity are applied.

(182) **Dynamo-electric Machines.**—During the years 1866–7, after the introduction of Wilde's machine and its exhibition before the Royal Society, where its powerful effects were fully demonstrated, Messrs. C. W. Siemens and Charles Wheatstone experimented independently of each other, and finally produced almost simultaneously two machines identical in principle and evolving a new feature in magneto-electricity. The machines were exhibited before the Royal Society on February 14, 1867, when they were fully described by the inventors. The following are the accounts given by each of their respective machines.

(183) **Conversion of Dynamical into Electrical Force without the Aid of Permanent Magnetism.**—Mr. C. W. Siemens states in his paper, received by the Royal Society on February 4 :—'Since the great discovery of magnetic electricity by Faraday in 1830, electricians have had recourse to mechanical force for the production of their most powerful effects ; but the power of the magneto-electrical machine seems to depend in an equal measure upon the *force expended* on the one hand, and upon *permanent* magnetism on the other.

'An experiment, however, has been lately suggested to me by my brother, Dr. Werner Siemens, of Berlin, which proves that permanent magnetism is not requisite in order to convert *mechanical* into *electrical* force ; and the result obtained by this experiment is remarkable, not only because it demonstrates this hitherto unrecognised fact, but also because it provides a simple means of producing very powerful electrical effects.

'The apparatus employed in this experiment is an electro-magnetic machine, consisting of one or more horseshoes of soft iron, surrounded with insulated wire in the usual manner, of a rotating keeper of soft iron, surrounded also with an insulated wire, and of a commutator connecting the respective coils in the manner of a magneto-electrical machine. If a galvanic battery were connected with this arrangement, rotation of the keeper in a given direction would ensue. If the battery were excluded from the circuit and rotation imparted to the keeper in the opposite direction to that resulting from the galvanic current, there would be no electrical effect produced, supposing the electro-magnet were absolutely free of magnetism ; but by inserting a battery of a single coil in the circuit a certain magnetic condition would be set up, causing similar electro-magnetic poles to be forcibly approached to each other, and dissimilar poles to be severed, alternately, the rotation

being contrary in direction to that which would be produced by the exciting current.

'Each forcible approach of similar poles must augment the magnetic tension, and increase consequently the power of the circulating current; the resistance of the keeper to the rotation must also increase at every step until it reaches a maximum, imposed by the available force and the conductivity of the wires employed.

'The co-operation of the battery is only necessary for a moment of time after the rotation has commenced, in order to introduce the magnetic action, which will thereupon continue to accumulate without its aid.

'With the rotation the current ceases; and if, upon re-starting the machine, the battery is connected with the circuit for a moment of time with its poles reversed, then the direction of the continuous current produced by the machine will also be the reverse of what it was before.

'Instead of employing a battery to commence the accumulative action of the machine, it suffices to touch the soft iron bars employed with a permanent magnet, or to dip the former into a position parallel to the magnetic axis of the earth, in order to produce the same phenomenon as before. Practically it is not even necessary to give any external impulse upon re-starting the machine, the residuary magnetism of the electro-magnetic arrangements employed being found sufficient for that purpose.

'The mechanical arrangement best suited for the production of these currents is that originally proposed by Dr. Werner Siemens in 1857,[1] consisting of a cylindrical keeper hollowed out at two sides for the reception of insulated wire wound longitudinally, which is made to rotate between the poles of a series of permanent magnets, which latter are at present replaced by electro-magnets. On imparting rotation to the armature of such an arrangement,[2] the mechanical resistance is found to increase rapidly to such an extent that either the driving-strap commences to slip, or the insulated wires constituting the coils are heated to the extent of igniting their insulating silk covering.

'It is thus possible to produce mechanically the most powerful electrical or calorific effects without the aid of steel magnets, which latter are open to the practical objection of losing their permanent magnetism in use.'—*Proceedings of the Royal Society*, vol. xv. p. 367.

(184) **On the Augmentation of the Power of a Magnet**

[1] See Du Moncel, *Sur Electricité*, 1862, p. 248.

[2] See Figs. 257, 258.

by the Reaction thereon of Currents induced by the Magnet itself.—Professor C. Wheatstone, F.R.S., communicated the following remarks to the Royal Society on the same date:—'The magneto-electric machines which have been hitherto described are actuated either by a permanent magnet or by an electro-magnet, deriving its power from a rheomotor placed in the circuit of its coil. In the present note I intend to show that an electro-magnet, if it possess at the commencement the slightest polarity, may become a powerful magnet by the gradually augmenting currents which itself originates.

'The following is a description of the form and dimensions of the electro-magnet I have employed. The construction, it will be seen, is the same as that of the electro-magnetic part of Mr. Wilde's machine:—

'The core of the electro-magnet is formed of a plate of soft iron 15 inches in length and $1\frac{1}{2}$ inch in breadth, bent at the middle of its length into a horseshoe form. Round it is coiled, in the direction of its breadth, 640 feet of insulated copper wire, $\frac{1}{12}$ of an inch in diameter. The armature, which is according to Siemens' ingenious construction, consists of a rotating cylinder of soft iron, $8\frac{1}{2}$ inches in length, grooved at two opposite sides so as to allow the wire to be coiled upon it longitudinally; the length of the wire thus coiled is 80 feet, and its diameter is the same as that of the electro-magnet coil.

'When this electro-magnet is excited by any rheomotor the current from which is in a constant direction, during the rotation of the armature, currents are generated in its coil during each semi-revolution, which are alternately in opposite directions; these alternate currents may be transmitted unchanged to another part of the circuit, or by means of a rheotrope be converted to the same direction.

'If now, while the circuit of the armature remains completed, the rheomotor be removed from the electro-magnet, on causing the armature to revolve, however rapidly, it will be found by the interposition of a galvanometer, or any other test, that but very slight effects take place. Though these effects become stronger in proportion to the residual magnetism left in the electro-magnet from the previous action of a current, they never attain any considerable amount.

'But if the wires of the two circuits be so joined as to form a single circuit, in which the currents generated by the armature, after being changed to the same direction, act so as to increase the existing polarity of the electro-magnet, very different results will be obtained. The force required to move the machine will be far

greater, showing a greater increase of magnetic power in the horse-shoe; and the existence of an energetic current in the wire is shown by its action on a galvanometer, by its heating 4 inches of platinum wire 0·0067 in. diameter, by its making a powerful electro-magnet, by its decomposing water, and other tests.

'The explanation of these effects is as follows:—The electro-magnet always retains a slight residual magnetism, and is therefore in the condition of a weak permanent magnet; the motion of the armature occasions feeble currents in alternate directions in the coils thereof, which, after being reduced to the same direction, pass into the coil of the electro-magnet in such a manner as to increase the magnetism of the iron core. The magnet, having thus received an accession of strength, produces in its turn more energetic currents in the coil of the armature; and these alternate actions continue until a maximum is attained, depending on the rapidity of the motion and the capacity of the electro-magnet.

'If the two coils be connected in such manner that the rectified current from the coil of the armature passes into the coil of the electro-magnet in the direction which would impart a contrary magnetism to the core, no current is produced, and consequently there is no augmentation of magnetism.

'It is easy to prove that the residual magnetism of the electro-magnet is the determining cause of these powerful effects. For this purpose it is sufficient to pass a current from a voltaic battery, a magneto-electric machine, or any other rheomotor, into the coil of the electro-magnet in either direction, and it will invariably be found that the direction of the current, however powerful it may eventually become, is in accordance with the polarity of the magnetism impressed on the iron core.

'If, instead of the currents in the coil of the rotating armature being reduced to the same uniform direction, they retain their alternations, no effects, or at most very small differential ones, are produced, as no accumulation of magnetism then takes place.

'I will now call attention to the fact that stronger effects are produced at the first moment of completing the combined circuit than afterwards. The machine having been put in motion, at the first moment of completing the circuit 4 inches of platinum wire were made red hot, but immediately afterwards the flow disappeared, and only about one inch of the wire could be permanently kept at a red heat. This diminution of effect was accompanied by a great increase of the resistance of the machine. The cause of the momentary strong effect was, that the machine, from its acquired momentum, continued its motion for a few seconds, though it required a stronger force than could be applied to maintain that

motion. Each time the circuit is broken and recompleted the same effect recurs.

'On bringing the primary coil of an inductorium (Ruhmkorff's coil) into the circuit formed by connecting the coils of the electro-magnet and rotating armature, no spark occurs in the secondary coil. On account of the great resistance of the circuit, which now also includes the primary coil of the inductorium, the current is not in sufficient quantity to produce any noticeable inductive effect.

'A very remarkable increase of all the effects, accompanied by a diminution in the resistance of the machine, is observed when a cross-wire is placed so as to divert a great portion of the current from the electro-magnet. The four inches of platinum wire, instead of flashing into redness and then disappearing, remains permanently ignited. The inductorium, which before gave no spark, now gave one a quarter of an inch in length; water was more abundantly decomposed; and all the other effects were similarly increased.

'I account for this augmentation of the effects in the following way:—

'Though so much of the current is diverted from the electro-magnet by the cross-wire, the magnetic effect still continues to accumulate, though not to so high a degree; but the current generated by the armature, passing through the short circuit formed by the armature-branch and cross-wire, experiences a far less resistance than if it had passed through the armature and electro-magnet branches; and though the electro-motive force is less, the resistance having been rendered less in a much greater proportion, the resultant effect is greater.

'I must observe that a certain amount of resistance in the cross-wire is necessary to produce the maximum effect. If the resistance be too small, the electro-magnet does not acquire sufficient magnetism; and if it be too great, though the magnetism becomes stronger, the increase of resistance more than counterbalances its effect.

'But the effects already described are far inferior to those obtained by causing them to take place in the cross-wire itself. With the same application of force, 7 inches of platinum wire were made red hot, and sparks were elicited in the inductorium 2½ inches in length.

'The force of two men was employed in these, as well as in the other experiments. When the interrupter of the primary coil was fixed, the machine was much easier to move than when it acted; for when the interrupter acted, at each moment of inter-

ruption the cross-wire being, as it were, removed, the whole of the current passed through the electro-magnet, and consequently a greater amount of magnetic energy was excited, while in the intervals during which the cross-wire was complete the current passed mainly through the primary coil.

'The effects are much less influenced by a resistance in the electro-magnet branch than in either of the other branches.

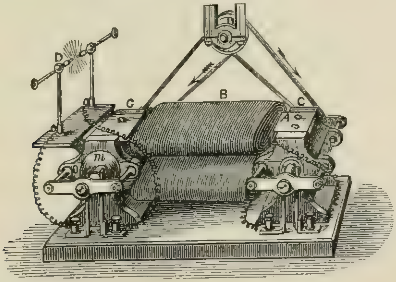
'To reduce the length of the spark in the inductorium (the primary coil of which was placed in the same wire) to $\frac{3}{4}$ of an inch, it required the resistance of $5\frac{1}{4}$ inches of the fine platinum wire in the cross-wire, 5 inches in the armature-branch, and 4 feet in the electro-magnet branch.

'When there was no extra resistance in either of the branches, the length of the cross-wire being only about a few feet, the intensity of the current in the electro-magnet branch, compared with that in the cross-wire, was as 1 : 60; and when the resistance of the primary coil of the inductorium was interposed in the cross-wire, the relative intensities were as 1 : 42.

'In conclusion I will mention that there is an evident analogy between the augmentation of the power of a weak magnet by means of an inductive action produced by itself, and the accumulation of power shown in the static electric machines of Holtz and others, which have recently excited considerable attention, in which a very small quantity of electricity directly excited is, by a series of inductive actions, augmented so as to equal, and even excel, the effects of the most powerful machines of the ordinary construction.'—*Proceedings of the Royal Society*, vol. xv. p. 369.

(185) **Ladd's Dynamo-electric Machine.**—The reactionary principle is fully developed in the machine introduced by Mr. Ladd

Fig. 259.



in 1867, and exhibited in Paris in that year: sundry improvements have, however, been made, but the diagram (Fig. 259) shows fully the principle.

In this there are, it may be said, no permanent magnets. It consists of two separate electro-magnets B B, consisting of slabs of soft iron, surrounded with insulated wire, as shown. C C are two frames or blocks, each bored out to take a Siemens armature M N. The current from the armature *n* is made to pass round the electro-magnets B B. The current from *m* is utilised to produce the electric light, as at D. The action of the machine is thus:—A voltaic current is passed once for all through the coils B B. This magnetises the plates A A, which, by a well-known law, retain a small quantity of magnetism ever afterwards. If, then, the armatures are put in motion by bands, as shown, a feeble electrical current will be set up in *m* and *n*, but the current from *n* running round the magnets A B, A B, makes them much more powerful than they were originally. They in their turn react more forcibly on *m* and *n*, and so the magnets go on reacting on themselves until very large quantities of electricity are produced. Thus the machine shown by Mr. Ladd in Paris in 1867 had the plates A A only 24 inches long by 12 inches wide, and was quite able to produce the electric light.

(185*a*) **Tisley's Dynamo-magneto-electric Machine.**—In 1867, after the production of the Siemens and Wheatstone experiments, Mr. S. C. Tisley designed a machine the principle of which was, that two separate armatures being introduced, one was employed for magnetising the machine, the other being used for external work. This machine gave a good electric light, &c., and was shown in the Paris Exhibition of 1867, where a silver medal was awarded. To simplify the machine Mr. Tisley placed the two armatures in the same groove, between the poles of the electro-magnet, bolting the two together at right angles to each other, so that they came under the influence of the magnetism alternately; by this method one pair of bearings was sufficient instead of two, and the machine altogether was much simplified.

A further modification was carried out in 1875, which is thus described by Mr. Tisley:—'The apparatus consists essentially of an electro-magnet, with shoes forming a groove, in which a Siemens armature is made to revolve. This is much the same as the original machines made by Siemens and Wheatstone, but the difference occurs in the break or commutator, where there are two springs or rubbers employed, taking the currents off from the commutator. The commutator consists of three rings. One of these rings is complete for three-quarters of the circle, the other quarter being cut away. Another ring is cut away three-quarters, leaving the one quarter. In between these rings is a third ring, insulated and connected with the insulated end of the wire wound round the arma-

ture; on this centre ring are projecting pieces, one a quarter of a circle, and the other three-quarters, so arranged as to complete the two outer circles.

The rubber spring which comes in contact with the quarter of the middle circle is connected with the electro-magnet of the machine, and the armature is so arranged that at the time of contact the best magnetising current is developed: the other spring-rubber is in connection with the wire on the armature during the other three-quarters of its revolution, and this is connected with any external piece of apparatus required to be worked. By this arrangement the alternate currents being utilised, they are all in the same direction, and by the length of contact the whole of the current is obtained in the best condition for heating wires, decomposing water, giving an electric light, and other usual experiments.

(186) **Siemens' Dynamo-electric Machine.**—The machines of this nature were until lately manufactured in a similar form to that of the machine exhibited by Dr. C. W. Siemens before the Royal Society, and which were employed for many useful purposes—blasting, magnetising, lighting, &c.—but recently a most important modification has been made, with the view of producing a more powerful machine for the purpose of lighthouse illumination. On June 5, 1873, Dr. C. W. Siemens, F.R.S., took out a patent, on a communication from abroad by Dr. Werner Siemens and Friedrich von Hefner Alteneck, of Berlin, 'for producing and regulating electric currents.' Comparative experiments have proved this machine to be the most powerful, and at the same time the least expensive, of all apparatus yet employed in the production of continuous electric light. It is a complete apparatus in itself, in which the core of the armature is fixed and the wire helix alone caused to rotate. By this means great inductive power is obtained, and consequently powerful currents are produced. With about 380 revolutions of the wire helix per minute, and nine to ten horse-power, a light equal to 14,000 candles can be obtained.

In this machine (Figs. 260, 261) the conductor, by the motion of which the electric current is produced, is of insulated copper wire, coiled in several lengths and with many convolutions, on a cylinder of thin German silver, and in such a manner that each single convolution describes the longitudinal section of the cylinder. The whole surface of the metal cylinder is thus covered with wire, forming a second cylinder closed on all sides *a*, *b*, *c*, *d*, (Fig. 261). This hollow cylinder of wire encloses the stationary core of soft iron (*n s*, *s′ n*, Fig. 261), which is fixed by means of an iron bar in the direction of its axis, prolonged at both ends through the

bearings of the wire cylinder to standards. Surrounding the wire cylinder for about two-thirds of its surface are the curved iron bars N N′, S S′, separated from the stationary iron core by space only sufficient to permit the free rotation of the wire cylinder. The

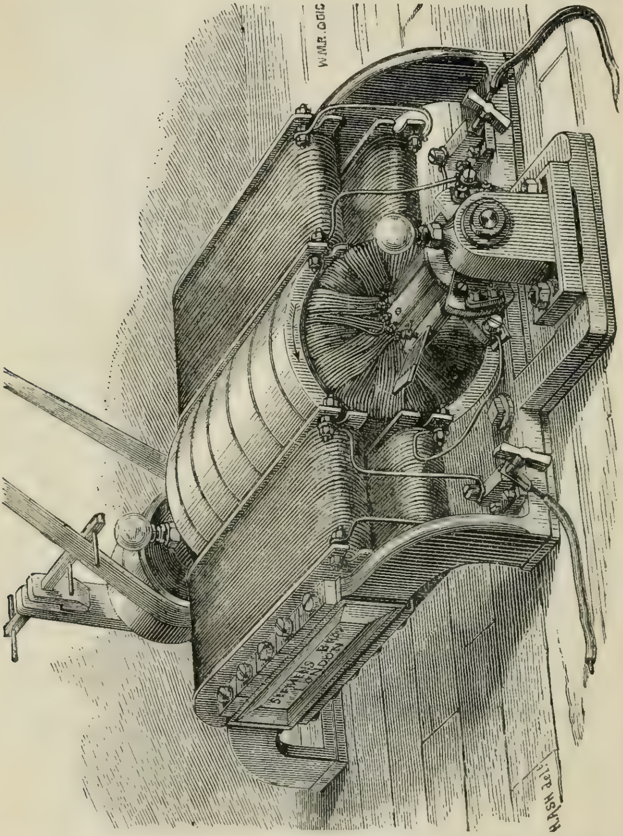


Fig. 260.

curved bars are themselves prolongations of the cores of the electro-magnets E E, E E, and the sides of the two horseshoe magnets N *o*–S, *m* and N′ *o*′–S′, *m*′ are connected by the iron of the two standards *o m* and *o*′ *m*′.

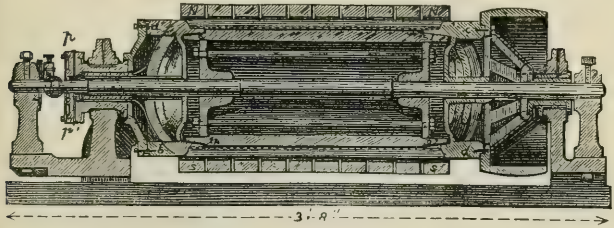
As the coils of the electro-magnet form a circuit with the wires

of the revolving cylinder, the revolution of the latter causes a powerful current to pass into the electro-magnetic coils, this again inducing a still more powerful current in the wires of the cylindrical armature. The iron core of the cylindrical armature, being very close to the poles of the electro-magnets, becomes itself an intensely powerful transverse magnet of opposite polarity to the electro-magnet. The cylinder of wire thus revolves in a very intense magnetic field.

The currents so generated are collected on two metal rollers or brushes, so that at two points diametrically opposite the single sectors pass under the rollers or brushes with elastic pressure, giving up to them their electrical charge.

A slight increase of speed in the rotation of the wire cylinder is followed by a considerable increase of current; but as the current increases so does the resistance to rotation, and this very rapidly. In addition to this heat is developed to such an extent that care

Fig. 261.



must be taken not to exceed a certain limit; otherwise the insulation of the coils would be destroyed. Were it not for this drawback almost any amount of current might be produced with suitable driving power.

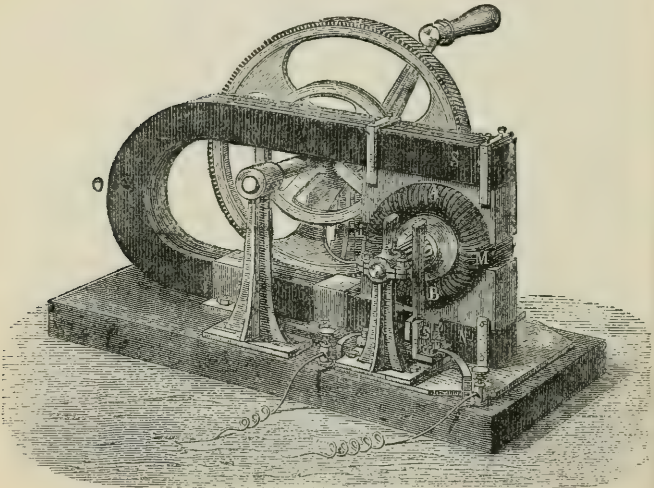
As the external resistance affects the strength of the current the speed must be varied accordingly, being greater as the external resistance is greater and *vice versâ*. With an electric lamp in a circuit of small resistance, if the machine is intended to work continuously, the revolutions of the wire cylinder per minute should not exceed 370 to 380. The temperature of the machine will then be at a maximum in about three hours, and during work will remain constant. At this speed the driving power is about eight indicated horse-power; while the intensity of the light, unaided by reflector or lens, has been shown by various photometers to be equal to 14,000 normal English candles. A more intense electric light cannot be obtained, as any increase in the current splits up even the best carbon.

Increased speed will of course compensate for decrease of current due to a too great external resistance, but this can be done only at the expense of increased motive power.—*Nature.*

(187) **The Gramme Magneto-electric Machine.**—The ordinary magneto-electric machines, previously described, produce but momentary currents, but by the machine invented by M. Gramme, of Paris, a continuous current is obtained. This result has been arrived at by the use of an improved armature, consisting of a ring of iron surrounded by coils of insulated wire.

In Fig. 262 we have a permanent horseshoe magnet O N S, be-

Fig 262.

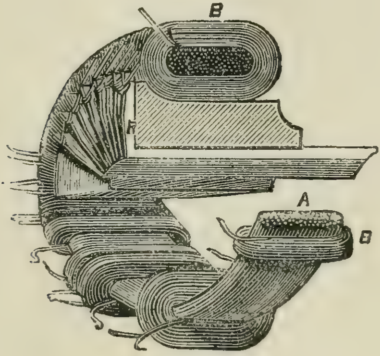


tween the poles of which is placed an armature or ring of soft iron, round which is wound a coil of insulated wire A B. The poles have pieces of iron fastened to them which completely overlap the ring, and allow it to revolve as close to the poles as possible. Now this ring is not a permanent magnet, but when placed in the position shown it is magnetised by induction by the permanent magnet N S. Two poles will then be established in the ring. If the ring be caused to revolve the position of the poles will remain unaltered in space, and it follows that every portion of the ring will alternately

become a north and a south pole. The consequence is that the poles may be regarded as constantly travelling through the iron ring at the same rate as that at which it revolves, but in an opposite direction.

In Fig. 263 one of the armatures or rings is cut open to show

Fig. 263.



its construction. The ring A is composed of a group of soft iron wires, which are found to work better than a solid bar. The wire is put on in separate coils, carefully insulated, as shown at B B. The radius pieces R R are insulated from each other by ribbons of silk or india-rubber. The end of the wire terminating one coil and the beginning of the wire of the next succeeding coil are each attached to one radius piece by loops and notches. The tails of the radius bars are all grouped together round the central axis, and they are rubbed against by suitable collectors, which take up the electricity.

The action of the Gramme machine may be explained as follows :—Let us regard the section of wire in the armature just above the line M M′ (see Fig. 262). The portion of the iron ring above this line—that is to say, the portion nearest the pole S—has the same polarity as that pole, whilst the portion of the ring below the line has northern polarity. Now, as the ring rotates the position of the ring above the line M M′ becomes more strongly south as it approaches S, and the part below less north as it recedes from N, and finally, when it arrives at S, the polarity is the same, which is

as much as to say that there is no magnetism in it. The change causes a current of electricity to be induced in the wire. As the ring now moves on towards N, the iron in front becomes a north pole, and that behind a south pole, until it arrives at the line M M′, when the difference of polarity is greatest. This change sends another current through the wire, which, as the ring has become turned over in position, will be in the same direction as the former one, or rather will be a continuation of the first current; so that the wire on the ring, in changing from M′ to M, has a continuous current induced in it, as have in like manner all the coils before and after it. As now the ring moves further still, the magnetism becomes less and less, as at first, and finally, when at N, disappears, and going on still further, becomes reversed as before. This causes a current to circulate through it in a reverse direction to the former one, and so also for all the coils before and after it. These currents together pass out through the studs, in contact with the spring, and return when the circuit between the springs is completed (as they must be, of course, before any current can flow) through the second spring, and thus a continuous current is kept up as long as the ring is kept rotating. The circuits of the machine are precisely similar to two sets of coils joined up for quantity—that is to say, the last zinc plate of one set joined to the last zinc of the other set, and also the last coppers joined together, each representing one separate coil. The electro-motive force of the current obtained from the Gramme machine is directly proportional to the rate of rotation of the coils—that is, when the rotation is not extremely rapid, for the demagnetisation of the iron requires a certain time. Fig. 262 shows a small machine rotated by hand; but very large machines have been made, driven by steam power, and used for lighting and other purposes.

The Gramme machine was first used to produce electricity for electro-plating. The first machine made was supplied to MM. Christofle et Cie, Paris, in 1872, and it ran for five years without any repairs or outlay, save the cost of oil for lubrication. Many other machines have been subsequently made, and the machine has been adopted by nearly all the great electro-plating firms.

A small Gramme machine was used successfully in this country for working telegraph circuits, and the larger machines have been used for the electric light.

(188) **Application of the Magneto-electric Machine to the Explosion of Mines and Submarine Charges.**—(*Report to the Secretary of State for War, by C. Wheatstone, F.R.S., and F. A. Abel, F.R.S., on the Application of Electricity from Different Sources to the Explosion of Gunpowder*):—

Fig. 264.

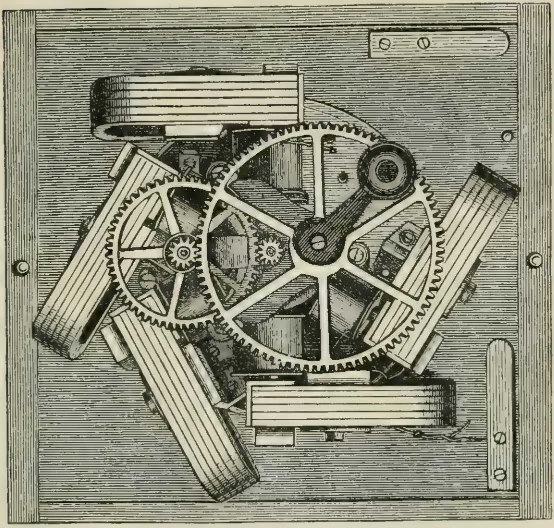
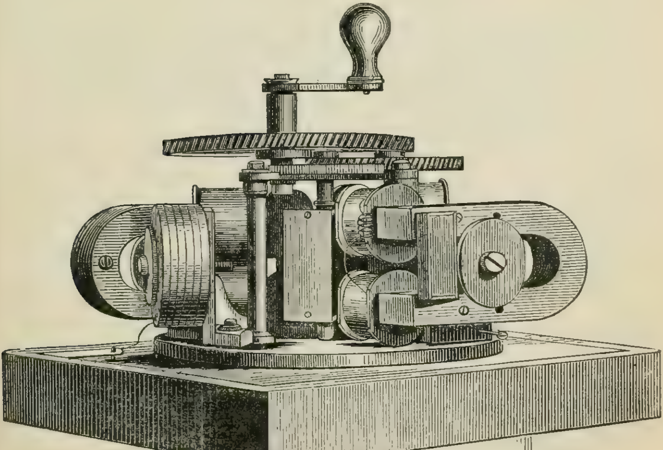


Fig. 265.



The Magnetic 'Exploder.'—This instrument (which has recently been rendered still more effective) was devised by Wheatstone; it effects the ignition at one time of fuses varying in number from two to twenty-five, under certain conditions. It consists of six small magnets, to the poles of which are fixed soft iron bars, surrounded by coils of insulated wire. The coils of all the magnets are united together so as to form with the external wire and the earth a single circuit. An axis carries six soft iron armatures in succession before each of the coils. By this arrangement, two advantages are gained: all the magnets simultaneously charge the wire, and produce the effect of a single magnet of more than six times the dimensions; and at the same time six shocks or currents are generated during a single revolution of the axis, so that when aided by a multiplying motion applied to the axis, a very rapid succession of powerful currents is produced. Another peculiarity of this apparatus is, that the coils are stationary, and the soft iron armatures alone are in motion; by this disposition the circuit during the action of the machine is never broken.

This ingenious instrument is shown in Figs. 264 and 265, one of the magnets having been removed to show the arrangement of the armature, &c.

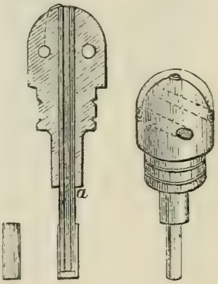
(189) **Siemens' Dynamo-electric Apparatus for Blasting, &c.**—The mechanical arrangement of this apparatus is similar to that proposed by Dr. Werner Siemens in 1857 for the production of electric currents, consisting of a cylindrical keeper hollowed at two sides for the reception of insulated wire wound longitudinally, which is made to rotate between poles of a small electro-magnet, having as its exciting agent its residual magnetism only. The electro-magnet is provided with a magnet-cylinder, within which revolves the Siemens armature.

The coils of this electro-magnet are traversed by the current produced by the rotating armatures after being, by means of a commutator, directed to flow in one direction only. At the commencement of rotation the armature is acted upon merely by the weak residuary magnetism of the electro-magnet, and consequently only weak currents are produced in its surrounding coil. These weak currents, as previously explained, passing through the coils of the electro-magnet in the same direction, instantly increase the magnetism, thereby again producing increased induced currents in the armature, and so on, until the iron of the electro-magnet has taken up the highest amount of magnetism which it is capable of holding. In this arrangement the coils are kept short-circuited, and so kept during the revolutions of the armatures until current and armature are developed to their utmost extent. By now

suddenly opening this short circuit, a very powerful current of short duration will pass through a line connected to the terminals. The throwing open of the circuit is arranged by an ingenious mechanical arrangement, which comes into play after a certain number of revolutions of the driving wheel, which is geared to a cog-wheel on the end of the armature. This machine has been found very successful as an 'exploder' of fuses.

(190) **Abel's Electric Fuses.**—The fuse for mining purposes consists of a head which is of boxwood, containing three perforations (Figs. 266 and 267); one, passing downwards through the centre, receives about two inches of double insulated copper wire *a*, enclosed side by side at a distance of one-sixteenth of an inch in a coating of gutta-percha; the other two perforations, which are parallel to each other on each side of the central one, and at right angles to it, serve for the reception of the circuit wires. The arrangement for securing the connection of these with the insulated wires in the fuses is as follows:—

Fig. 266. Fig. 267.



The piece of double covered wire above referred to is originally of a sufficient length to allow of the gutta-percha being removed from about one-and-a-half inches of the wires. These bare ends of the fine wires, which are made to protrude from the top of the fuse-head, are then pressed into slight grooves in the wood provided for their protection, and the extremity of each is passed into one of the horizontal perforations in the head, in which position it is afterwards fixed by the introduction into the hole of a tightly-fitting piece of copper tube, so that the wire is firmly wedged between the wood and the exterior of this tube, and thus at the same time brought into close contact with a comparatively large surface of metal. It will be seen that it is only necessary to fix one of the circuit wires into each of these tubes in the opposite sides of the fuse-head in order to ensure a sufficient and perfectly distinct connection of each one of them with one of the insulated wires in the fuse.

The extremity of the double covered wire, which protrudes to the distance of about three-quarters of an inch from the bottom of the fuse-head, is provided with a clean sectional surface, by being cut with a pair of sharp scissors, care being taken that the extremities of the fine copper wires are not pressed into contact by this operation. A small cap of about half an inch in length is

then constructed of thick tin-foil, into which is dropped about one grain of the priming material. The double wire is then inserted, and pressed firmly down into the cap, so that the explosive mixture is slightly compressed, and in close contact with the surfaces of the terminals. The cap being secured with twine, the fuse is ready for enclosure in a small charge of gunpowder. The powder is contained in a paper case tied on to the head, or in a cylinder of sheet tin, tightly fitting on the fuse-head at one end ; the other, after the introduction of the powder, being closed with a plug of clay or plaster of Paris (Figs. 268 and 269). The fuses, as they are manufactured, are fitted with two pieces of covered wire twisted together (Fig. 270), which are tightly fixed into their proper positions by forcing a short pin of copper wire into the holes of the fuse-head. They are thus ready for insertion into the bag or other receptacle containing the charge of gunpowder, the ends of the covered wires protruding from the opening of

Fig. 268.

Fig. 269.

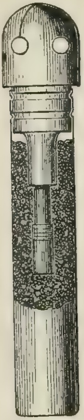


Fig. 270.

the latter to a convenient distance, for effecting the junction with the branch and earth wires.

The fuse for firing cannon (Fig. 271) differs somewhat in construction from the mining fuse. The head is somewhat longer, and of such a form that the double covered wires are completely enclosed in it, the lower extremity of its central perforation still remaining free to receive the top of the quill or copper tube, which is charged with gunpowder in the same manner as the ordinary tube arrangement for firing cannon.

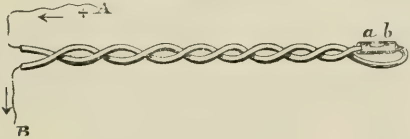
The Priming Material.—When a copper wire has been covered with vulcanised gutta-percha for some time, the surface of the metal becomes covered with a layer of sulphide of copper, which is a moderately good conductor of electricity. It was discovered by Statham that advantage may be taken of this fact to construct convenient fuses for firing gunpowder.

Let A B (Fig. 272) represent a copper wire thus covered, but from which the upper surface of the coating is removed, and the wire interrupted from *a* to *b*. If a current of electricity of sufficient tension be caused to circulate through the wire, it will leave the wire at the point *a* and pass through the sulphide of copper, but here sufficient resistance will be set up to ignite the sulphide: consequently, if the cavity between *a* and *b* be filled up with gunpowder or guncotton, it will take fire. This fuse was successfully employed in exploding mines in the works of Cherbourg, a Ruhmkorff's coil, excited by two of Bunsen's cells, being the power employed.

Fig. 271.

With a Statham's fuse charged with fulminate of mercury, Colonel Verdu effected a simultaneous explosion of six mines in the circuit, at a distance of 300 metres from the apparatus, a coil excited by a single element of a Bunsen's battery being employed. It was found, however, by Wheatstone and Abel, that the electro-magnetic induction machine was subject to considerable irregularity; that the conductor became liable to derangement in the transport of the apparatus, and that the apparatus was so liable to injury from such a variety of causes, as not to be recommended with confidence for field purposes; they therefore suggest, in preference, the magneto-electric machine.

Fig. 272.



The ignition of gunpowder by the direct magneto-current cannot be effected with any degree of certainty, and even Statham's fuses cannot be depended upon. The priming material discovered by Abel, which greatly exceeds in sensitiveness any other composition, is prepared by reducing separately, to the finest possible state of division, *sub-phosphide of copper*, *sub-sulphide of copper*, and *chlorate of potassa*, and then mixing these powdered substances very intimately in the proportions of 10 parts of the first, 45 of the second, and 15 of the third, by rubbing them well together in a mortar, with the addition of sufficient alcohol to thoroughly moisten the mass. The mixture is afterwards carefully dried, and may be safely preserved in close vessels till required.

Statham's fuse was originally discovered by accident; a slight

break, or rather want of continuity, had occurred in a piece of ordinary guttapercha-covered wire, due to the action of the sulphur, which was formerly used in the preparation of the gutta-percha, on the copper conducting wire; this had produced a decomposition of the latter, leaving a minute break in the conductor filled, however, with sulphide of copper, and it was noticed that on the passage of an electric current through the comparatively bad conductor thus introduced into the break, great heat was produced, by which powder could be fired. This illustrates the general principle on which all fuses to be fired by a current of electricity of high tension are constructed—namely, a minute break in the wire conductor, into which a chemical compound, or mixture of compounds, is introduced in such a way that the current must pass through it, and produce heat sufficient to fire a priming charge in contact with it.

In applying the electric spark to the explosion of fuses, the distance from each other of the metallic points, between which the spark passes, must be adjusted with great nicety; it is also important, when a number of charges are to be exploded in divided circuit by means of a constant battery or magneto-electric machine, that no residue should be left between the poles after the explosion of the fuses, which would still serve to conduct the spark across the interval. The composition discovered by Mr. Abel completely fulfils the latter condition, and the former is ingeniously secured in the construction of the fuse by means of an arrangement of double-covered, insulated wire, by which the distance between the wire points is very uniformly established.

(191) **Von Ebner Fuse.**—Another fuse of the above nature, more recently devised, is that of Baron von Ebner, general in the Austrian corps of engineers. The priming in this fuse consists of a mixture of equal parts of sulphuret of antimony and chlorate of potassa. A small quantity of powdered plumbago was formerly introduced into the composition, with a view of giving a certain amount of conductivity for testing purposes; it was, however, found to act prejudicially, occasionally giving too much conducting power, and rendering the ignition of the fuse somewhat uncertain: it has consequently been discontinued.

(192) **Beardslee Fuse.**—Another form of fuse, adapted for currents of high tension, is that devised by Mr. Beardslee, of New York. In this fuse the bridge is formed by means of plumbago, together with a small quantity of a substance which importantly assists the plumbago in its action, the nature of which has, however, not been disclosed. This fuse, though adapted for a current of high tension, partakes more of the nature of the platinum-wire

fuse, having a metallic bridge, which is, so to speak, burnt by the action of the electric current passing through it.

(193) **Abel's Submarine Electric Fuse.**—The very delicacy and sensitiveness of Abel's ordinary fuse renders it a somewhat difficult, and, without extreme skill and care, even a dangerous, operation to test it after being placed in position in a mine, as there is a certain chance of involuntarily exploding the charge while passing a test current through it. Under these circumstances Mr. Abel undertook to devise another form of fuse for submarine mining purposes, and his labours have met with perfect success. His new fuse, called the 'submarine electric fuse,' is constructed as follows:—

The bridge consists of a very intimate mixture of graphite and fulminate of mercury. The mixture is compressed into a cavity into which the fuse terminals slightly project. The electrical conducting power of this mixture is regulated by ramming it as tightly as possible, till it offers the particular resistance required; the attainment of this object is determined by keeping a feeble current circulating through the fuse, with a galvanometer in circuit, during the ramming process. In this way he has been able to manufacture fuses of very uniform electrical resistance, which can be tested with perfect safety and which fire with great certainty.

(194) **Low-tension Fuses.**—Since the introduction of the Abel submarine electric fuse, Professor Abel, F.R.S., has been actively engaged in making experiments and investigations into the material and quality of the wire usually used as the bridge for low-tension fuses; from these experiments he arrived at the following conclusions:—

1. Both the German-silver and the platinum-silver alloy are greatly superior to platinum in regard to the resistance opposed to the passage of a current, and the heat consequently developed in given lengths of wire of a particular diameter.

2. German-silver is, in its turn, superior in this respect to the platinum-silver alloy, as is especially apparent in the finest wires. This superiority, though very marked in considerable lengths of wires of the same diameter, is, however, only trifling in short lengths; the comparatively ready fusibility of the platinum-silver wire contributing, with other physical peculiarities of the two alloys, to reduce the fine German-silver wire to about a level with it, and sometimes even to a somewhat lower level as regards the thermal effects produced. Some slight influence in this direction may perhaps also have been exerted, in these particular experiments, by the greater cooling power exerted, by the brass supports

between which the wires were fixed upon the German-silver wire of comparatively low specific gravity.

The following further interesting remarks were made by Professor Abel, F.R.S., in a paper read by him before the Society of Telegraph Engineers in May 1874:—' In selecting a wire for the construction of low-tension fuses, its power to resist corrosion when in intimate contact with gunpowder or other substance employed as the igniting medium in such fuses, especially if some moisture should be accidentally absorbed by them, possesses an important bearing upon its permament efficiency. In Matthiessen's report on the application of platinum-silver wire to the preparation of standard resistance-coils, it is stated not to oxidise by exposure to air; it has, however, been observed to do so gradually, to the extent of becoming tarnished, and as, with extremely fine wires, a very superficial oxidation might appreciably affect the resistance of fuses constructed with them, it was thought desirable to ascertain by actual experiment, of a somewhat severe nature, the power of such wires to resist corrosion in comparison with German-silver wire. It was, of course, unnecessary to experiment with platinum wire in this direction. Wires of the two alloys, about eight inches long, were enclosed in glass tubes, and each wire was surrounded closely by gunpowder and guncotton in the ordinary air-dry condition, one of each being also simply closed in air for purposes of comparison. In addition a length of about two inches of each kind of wire was buried in wet gunpowder, the extremities being allowed to protrude sufficiently for testing purposes. The resistances of these specimens were periodically examined, with the following results:—In all three experiments with the German-silver wires enclosed in tubes there were indications of very slight superficial oxidation, as demonstrated by the permanent, though small, increase in the resistance of these wires, which, in the case of its exposure to contact with guncotton, continued very gradually up to the forty-first day, when it became stationary. The resistance of the platinum-silver wires in glass tubes remained constant throughout.

'The exposure of the wires in contact with *wet* gunpowder has afforded very marked evidence of the greater liability of the German-silver wire to corrosion; at the same time it must be borne in mind that this test far exceeds in severity any conditions under which fuses constructed with wire bridges would be likely to be preserved in actual practice. It will be seen that the platinum-silver wire remained unaffected by this test thirty-two days after the continuity of the German-silver wire had been destroyed by corrosion. The great influence of the charcoal in the

gunpowder in promoting corrosion in its capacity as an electrolyte is interestingly demonstrated by the fact that the German-silver wire remained buried for twenty-two days in wet saltpetre without undergoing great oxidation (which oxidation did not progress after that time), while the wire which was buried in wet gunpowder was destroyed by corrosion within six days.'

The following remarks relating to the construction of low-tension or wire fuses conclude the interesting and most valuable paper of Professor Abel:—

'It need hardly be stated that uniformity in resistance is an important quality to be arrived at; it is, moreover, a quality the attainment of which does not solely depend upon the employment of a wire of uniform conductivity, but also demands careful attention to details in the construction of the wire bridge, and in the application of the igniting material or 'priming' round the bridge, the necessity for such care increasing with the fineness of the wire employed in the fuse.

'Uniformity in the resistance of wire fuses made with one particular kind and size of wire depends obviously in the first instance upon the employment of the same length of wire as the bridge in each fuse. With a view to attain this end the copper terminals must be accurately fixed at the same distance apart in the several fuses: the wire must be always uniformly stretched across between these terminals (and therefore strained from one to the other as tightly as possible), and its two extremities must be attached to the terminals as uniformly as possible. The following general directions for constructing the terminals and wire bridge will indicate the manner in which uniformity in the resistance of the fuses may be attained:—

'The bared ends of the insulated copper wire which are to form the terminals are firmly fixed at a uniform distance apart (0·25 inch is found a very convenient distance) by being inserted into a die or mould, and partly embedded, while in that position, in a plug of some very hard cement or composition, which attaches itself thoroughly to the copper surfaces. A mixture of plaster of Paris or Portland cement and sulphur, which is cast round the wires while sufficiently hot to be viscid, is a good material for the purpose; or the wires may be embedded in a plug of india-rubber preparation of the proper composition for subsequent conversion into ebonite. In either case the sulphur, which is a component of both preparations, attacks the surfaces of the copper wires, and thus ensures their being quite immovable when the plug has cooled. The bare ends, or terminals, should project about 0·25 inch beyond the plug in which the wires have been fixed, and

should be uniform in length and well brightened. In stretching the fine wire across from one terminal to the other, pains should be taken to do this always as tightly as possible, and in a perfectly horizontal line, so as to ensure the employment of uniform lengths of wire in different fuses Means should be adopted for making the terminals hold the wire, by the obvious expedient of roughening the surfaces of the copper, or of cutting a fine slit into their extremities, into which the wire may be inserted. The latter should, when properly strained and wrapped round, or let into the terminals, be firmly attached to these with solder, carefully applied by means of a small rod to *the back* of the terminals, so as not to be brought into contact with the wire bridge itself.

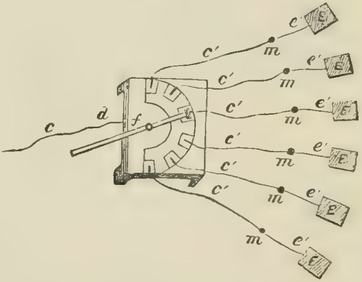
'Either guncotton or gunpowder is now very generally employed as a *priming* agent in platinum-wire fuses—*i.e.* as a means of facilitating the production of explosion by such fuses—because the heat developed on passing a current through a fuse, if it should be insufficient to melt the wire, or to raise it to the temperature necessary for the ignition of gunpowder, may yet suffice to ignite the comparatively readily explosive guncotton. A small tuft of guncotton wool is generally pressed round the wire bridge, or a piece of guncotton yarn is tied upon it; but though either of these modes of applying the guncotton priming can be readily used in fuses containing the comparatively coarse and strong wire hitherto employed, they are not so easily applicable in conjunction with fine wires, as these are liable to be broken in the operation, or as, for fear of this occurring, the priming is not brought into properly close contact with the whole of the bridge, a condition which increases in importance as the source of heat in the fuse is diminished by a reduction of the thickness of the wire. A simple modification in the mode of applying the guncotton ensures a thoroughly efficient priming of the fuse, without any risk of the fracture of the bridge being incurred. A very fine guncotton powder or dust is prepared by taking dry pulped guncotton, or compressed guncotton, scraped or broken up to powder, and sifting this through muslin; the dust thus obtained is intimately mixed by means of a feather or hair pencil with sufficient mealed gunpowder or detonating powder to make it flow readily into a small cavity. When the bridge of the fuse has been fixed in position into the fuse-head or case, this priming powder may be poured in and made to surround the bridge thoroughly and compactly by gently tapping or shaking the case, without the slightest risk of breaking the bridge.

'There is no doubt that, by combining care in construction of the fuse with the employment of fine wires of the nature referred

to, the low-tension or wire fuse attains a degree of sensitiveness and uniformity which must render it a formidable, and in many instances a very successful, rival of the high-tension fuse in directions in which hitherto the latter has been pre-eminent for efficiency, more especially in connection with the employment of simple, powerful, and portable electrical appliances for the explosion of mines.'

(195) **Verdu's Rheotomic Arrangement of the Charges.**—The discharge from the induction-coil machine, unlike that from the Leyden jar, which will pass through several hundred solutions of continuity, producing a spark at each interruption, becomes so enfeebled by successive interruptions in the metallic circuit, that it is impracticable to ignite with certainty a number of charges in one circuit beyond certain limits, which, with Statham's fuses, are very narrow. Verdu, therefore, arranged the mines to be fired in groups, so that each group formed a special circuit; by then bringing each circuit in very quick succession in connection with the instrument, the mines were discharged with a rapidity which had the practical effect of a simultaneous discharge. One of the arrangements adopted is shown in Fig. 273, where *c* represents a wire connecting one pole of the induction coil with an instrument *d*, called a rheotome, the other pole being connected with the earth. The rheotome is provided with binding screws for receiving the separate wires *c′*, which lead to the mines *m*. These screws are fixed into small copper plates isolated from each other, being either let into the wood or separated by strips of glass. The wire *c* from the coil machine is in connection with a sort of metallic finger *f*, which, by means of an insulating handle, may be made to describe a semicircle with any degree of rapidity that may be required; and as its one extremity presses firmly upon the instrument at a point near any one of the binding screws, it is brought alternately into contact with the several small plates with which they are connected, thus bringing them (and therefore the mines) into connection with the coil machine. The wires *e′* and the plates

Fig. 273.

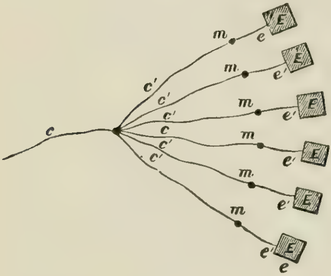


of metal E connect the charges and the coil machine with the earth.

(196) **Savare's Arrangement of the Charges in Divided Circuits.**—By dividing the circuit into branches, over the whole of which a current, or a rapid succession of currents, are distributed on the completion of the circuit, as was first suggested by M. Savare, a method of securing a practically simultaneous discharge of a number of mines more effective than the so-called *rheotomic* arrangement of Verdu is obtained.

The arrangement is shown in Fig. 274 (the letters of reference in which correspond in their meaning to those in Fig. 273); the principal difference is that the rheotome is dispensed with, and the wires are connected directly with the wire leading to the machine. On interposing one or more fuses in each branch of the circuit, those which happen to offer the greater facilities in their construction to the passage of the current will explode first, and the fuses being so constructed that the terminals of the wire in them are forced apart by the explosion, or fused by the heat generated, the further passage of the current in that direction is prevented, and the remaining fuses are in their turn exploded. Experiments with this mode of discharge were first made at Grenoble in 1854.

Fig. 274.



It was found by Wheatstone and Abel that even with the sensitive detonating mixture discovered by the latter, the current obtained from a powerful magneto-electric machine was very limited in its powers when applied to the ignition of several charges arranged *in succession* in one circuit; but by arranging the charges in divided circuits, the ignition of twenty-five charges could be with certainty effected by the current obtained from a small horseshoe magnet, 7 inches in length, 1 inch in breadth, and 1¾ inch in thickness, provided with a revolving armature and multiplying wheels, and by means of Wheatstone's magnetic exploder (Figs. 264, 265), twenty-five charges could be fired in divided circuit with such rapidity that the effect on the ear was as of one explosion.

(197) **Theory of the Magneto-electric Machine.**—As often

as the bent ends of the armatures or inductors F, F, F (Figs. 248, 249, 250) are by the rotation of the wheel brought opposite the poles of the magnet, they become magnetic by induction; but being soft iron, they lose their magnetism when they are in the position shown in Fig. 248—*i.e.* at right angles to the magnetic poles. Now, we have seen (170) that at the moment of the *induction* as well as of the *destruction* of the magnetism in an iron bar surrounded by copper wire, currents or waves of electricity, moving however in opposite directions, are induced in the wire, if the circuit be complete; the points k (Fig. 248) are, therefore, so arranged that they shall leave the mercury, and thus break the circuit in the wire surrounding the armature F, at the moment that its ends become opposed to the poles of the magnet; for which purpose they must be placed at nearly right angles to it: the circuit is thus broken at the precise moment that a rush or wave of electricity is determined in the wire, and hence the electrical effects that are obtained.

The laws which regulate the magneto-electric force excited by magnetism in the induction coils have been investigated by Lenz, and his results agree with those which, in conjunction with Jacobi, he had previously found to regulate the intensity of the electro-dynamic force excited by voltaic currents.

These laws are:—

1. That the magneto-electric energy in an induction spiral, by means of magnetism, is equal to the sum of the electro-motive forces of all the individual coils of the wire; this is in accordance with the fundamental law of Ohm (108).

2. That with equally powerful currents the magneto-electric force will be nearly proportional to the number of coils, the thickness of the wire exerting no influence on it; the intensity will, however, be slightly diminished by increasing the width of the coils.

(198) **The Extra Current.**—If a small pair of voltaic plates be moderately excited, and a small short wire used to connect its mercury cups, no spark, or only a very minute one, will be perceived either on making or breaking contact. As, however, the length of the connecting wire increases, the spark becomes proportionally brighter, until, from extreme length, the resistance offered by the metal begins to interfere with the principal result.

If two equal lengths of wire be taken, and one made up into a helix and the other laid out upon the floor, and if each be used to connect the mercury cups of a small battery, a very great difference will be observed in the size of the spark afforded by each on breaking contact. Suppose the length of each to be 60 feet, the wire laid on the floor will give a small bright spark, while the wire

wound in a helix will produce a brilliant spark, accompanied by a snap.

Again, to render the fact still more decisive, let 100 feet of covered copper wire be bent in the middle so as to form a double termination, which can be connected with the battery. Let one half be wound into a helix, and let the other remain in its extended condition; use these alternately as the connecting wire, and the helix will be found to give by far the stronger spark.

The spark and the snap are much increased when a bar of soft iron, or a bundle of soft iron wires, is introduced into the axis of the helix; the reason being, that the iron, which becomes magnetised by the power of the continuing current, loses its magnetism at the moment the current ceases to pass, and in so doing tends, as we have already seen (172), to produce an electric current in the wire round it.

Now, we have already seen (171) that if two wires be placed parallel to each other, and a current from a voltaic battery established in one, a wave of electricity in the same direction is induced in the other the moment the current ceases to flow through the first. Under these circumstances (the second wire forming a complete circuit) the spark on breaking battery contact is very feeble, far less than if the second wire were away, for in the latter case the wave which on breaking contact would have been induced in the second wire is now *induced in itself*.

If the inductive action of a wire a foot long upon a collateral wire also a foot in length be observed, it will be found to be very small, but if the same current be sent through a wire 50 feet long, it will induce in a neighbouring wire, also 50 feet long, a far more powerful wave of electricity at the moment both of breaking and making contact; a similar effect should obviously take place when the conducting wire is also that in which the induced current is formed; hence the reason why a long wire may give a brighter spark than a short one, although it may carry less electricity. If the long wire be made into a helix, it will be still more effective in producing sparks on breaking contact, for by the inductive action of the convolutions each aids its neighbour, and is aided in turn, and the sum of effects is in consequence greatly increased.

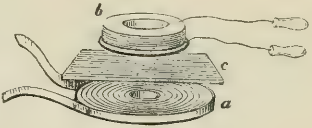
The current which a wire thus induces in itself is called the *extra* current; that produced on making battery contact is in direction *contrary* to that of the principal current, and is called the *inverse* extra current; that produced on breaking battery contact is in the *same* direction as that of the principal current, and is called the *direct* extra current.

(199) **Henry's Coils; Secondary Currents.**—The waves or

currents of electricity thus induced are capable of giving powerful shocks, of magnetising steel bars, and of producing chemical decomposition.

Let *a* (Fig. 275) be a ribbon of copper covered with list or silk, about 100 feet long and 1 inch wide; and let *b* be a helix of fine covered copper wire about 1,500 yards long; let *b* be placed on *a*, a plate of glass intervening; let the experimenter grasp the metallic handles attached to the ends of the coil, whilst an assistant makes and breaks contact between the ends of the ribbon and a small simple voltaic battery, powerful shocks will be experienced every time the rupture is made and the contact renewed, which, unless the battery be very small, may be excruciating.

Fig. 275.



Dr. Henry, of New Jersey, to whom we are indebted for a very elaborate investigation of the phenomena of induced electrical currents, constructed a ribbon coil 300 feet long and $1\frac{1}{2}$ wide, and helix of copper wire *five miles* long. With this apparatus shocks could be obtained when the coil and the ribbon were four feet apart, and at a distance of twelve inches they were too strong to be taken through the body.

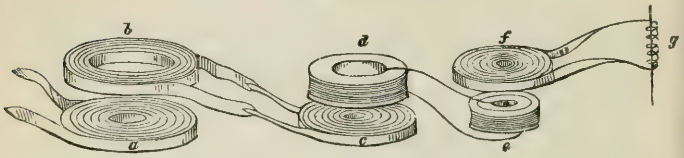
If, instead of the helix of thin copper wire *b*, a ribbon similar to *a* be employed, then powerful shocks can no longer be obtained. The induced current has the properties of one of considerable *quantity*, but of moderate *intensity*. Sparks are produced when ends of the secondary ribbon are rubbed together. When a small coil of wire enclosing a needle is interposed, the needle becomes magnetic; a piece of soft iron is temporarily magnetised, and water is decomposed.

(200) **Currents of the Third, Fourth, and Fifth Orders.**—Dr. Henry arranged a series of ribbons and coils in the manner shown in Fig. 276. On transmitting an intermitting voltaic current through *a*, a secondary current is, as we have seen, induced in *b*, placed at a distance above it. Now, this secondary current, by passing through the third ribbon coil *c*, induces a current of the *third* order in the helix *d*; and this coil again, by passing through the helix *e*, induces a current of the *fourth* order in the ribbon coil *f*, as is proved by the power it possesses of magnetising a needle in the small helix *g*. Henry further determined that there existed an alternation in the direction of the currents of the several orders, commencing with the secondary; it was as follows:—

Primary current a (on making), direct.
Secondary current $b\ c$ (on making), *inverse*; (on breaking), *direct.*
Tertiary current $d\,e$ (on making), *direct*; (on breaking), *inverse.*
Quaternary current $f\,g$ (on making), *inverse*; (on breaking), *direct.*

and so on, currents even of the *seventh* order having been obtained, the successive currents being alternately direct and inverse.

Fig. 276.



The current induced f by the helix g is one of *quantity*; but the effects of the induced tertiary current in d are those of intensity, and by grasping metallic handles attached to the ends of that helix, shocks may be received. Thus a quantity current may be induced from one of intensity and the converse. Henry found also that on interposing a screen of any conducting substance between a and b, no secondary currents could be obtained: a circular plate of lead, for instance, caused the induction in b almost entirely to disappear; but when a slip of the metal was cut out in the direction of a radius of the circle, the induction was not in the least interfered with.

Again, the coil b being placed upon a, with the two ends separated, and on the coil the helix d, shocks could be obtained from the latter as if the coil were not present; but when the ends of b were joined, so as to form a perfect metallic circuit, no shocks could be obtained. These effects were referred by Henry to the changes in the direction of the induced currents; the secondary current which is induced in the screening-plate or closed ribbon coil, is, on breaking contact, in the same direction as the current from the battery; it nevertheless tends to induce a current in the adjacent conducting matter in a contrary direction. A similar reaction, as it were, may be observed by placing on a flat ribbon coil another similar coil, and then taking the shock from the first when the ends of the second are joined, the intensity will be found to be greatly diminished; although, if the ends of the second coil be not joined, no difference in the intensity of the shock will be perceived.

(201) **Electro-magnetic Coil Machines.**—The instruments

that have been constructed for the exhibition of the intense electrical currents or waves obtained by magneto- and volta-electric induction, have assumed a variety of forms, and the battery contact is broken and renewed in a variety of ways. Some of these machines are shown in Figs. 277, 278, 279, and 280.

In Fig. 277 the primary coil is about 35 feet long, and the secondary about 1,400 feet; battery contact is broken and renewed by the rotation of a soft iron bar *h*, which, mounted between two brass pillars, is situated immediately over the axis of the coil in which is placed a bundle of soft iron wires. The current from the battery passes through the pillar *d* and the axis carrying the iron bar, and contact is broken and renewed by the point *i* dipping as *h* revolves into and out of the mercury contained in the brass cup *g*, which is mounted on the brass pillar *a*, through which the circuit is completed; communication with the voltaic pair is established through the binding screws at the base of the apparatus.

Fig. 277.

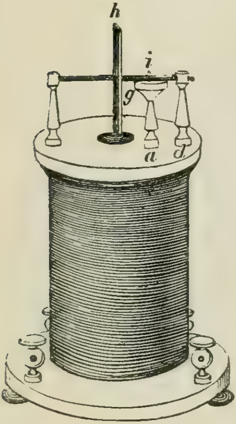
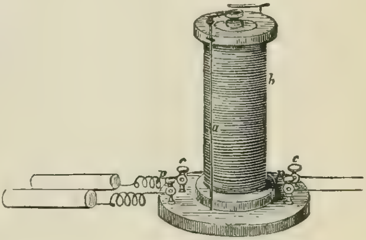


Fig. 278.



In Fig. 278 the current from the battery passes from the binding screw *p* up the wire *a*, which terminates in a small disc of iron arranged immediately over the bundle of iron wires in the axis of the coil, from which it is prevented from coming immediately into contact, when the machine is not in action, by the horizontal spring by which it is connected with the wire *a*. The binding screw *c* is connected with the wire *b*, the top of which is seen in the figure rising above the coil. On the top of this wire is a horizontal slip of metal tipped with platinum, and with this, by the action of the spring, the disc of iron is kept in contact. Now, when connection is made with the battery through the wires *p* and *c*, the central core of iron wire becomes magnetised, and consequently attracts the disc of iron, thus breaking battery contact: the current being shut off, the disc of iron is again raised by the spring, and thus contact is broken and renewed with amazing rapidity.

In Fig. 279 the contact breaker is a curved spring *c*, which is carried rapidly round by the multiplying wheel and handle *d* striking in its course against the notches in the interior of the metallic circle *b*. This circle must have an odd number of teeth or notches in order that the ends of the S-shaped spring may produce the spark at the opposite parts of the ring. The diameter of the ring *a b* may be about 5 inches; they may be made of different metals, and secured in the circular rabbet of the square piece of wood A by small turn buttons. One end of the primary coil is in communication with the ring, the other is in connection with the binding screw *b*, where one of the battery wires is to be fixed. The spring *c* has a metallic communication with the other pole of the battery by means of its metallic socket, to which a wire is soldered and brought down to another connecting piece symmetrical with *e*, but not shown in the figure; *f f* are the usual connecting pieces for administering the shock, &c. If the ring has a diameter of 12 inches, and if a tolerably strong battery be employed, very brilliant effects are produced.

Fig. 280.

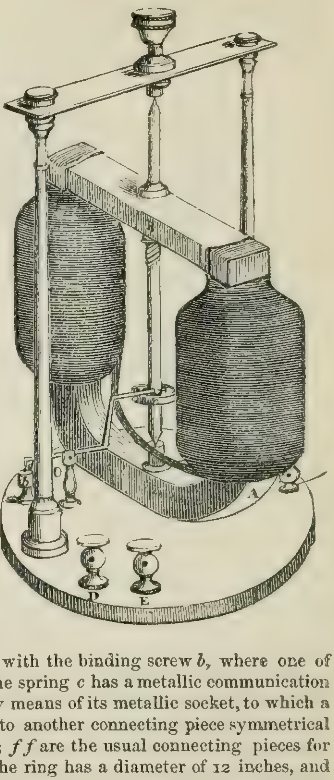


Fig. 279.

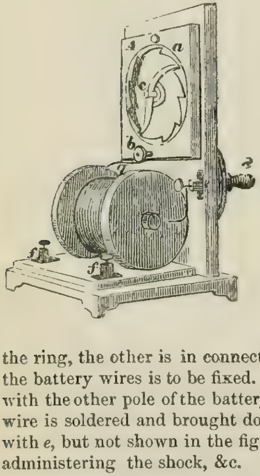


Fig. 280 represents Henley's powerful arrangement of the electro-magnetic coil machine. A is a series of U-shaped bars of soft iron, wound with 4 coils of No. 14 covered copper wire to within an inch of either extremity; over this are wound 1,000 yards of No. 34 covered wire in one continuous length. B is the revolving armature which rotates between the poles of the magnet fixed on an axis, the lower end resting on a hard steel cap, the upper kept in its position by a screw passing through a flat piece of metal mounted on two brass columns. O is the apparatus for breaking contact, consisting of a small lever *a* suspended on a pillar, one end dipping into a mercury cup *b*,

and the other provided with a friction roller, running on an undulating wheel *c*, the prominent part of which, raising the end of the lever, dips the other end into the mercury; a spring *d* raising it out when the roller falls on the lower parts of the wheel. D and E are the binding screws for forming connection with the battery; the opposite screws are the ends of the secondary coil. On the same side of the base as the last (not seen in the woodcut) is an ivory knob which, being turned, connects the ends of the secondary coil, either to diminish the primary spark, as the armature will then rotate for hours without burning the mercury, or to prevent the operator from receiving an unpleasant shock while adjusting the instrument. With an intensity series of 8 cells of Smee's battery, the secondary current produces a spark passing through one-eighth of an inch of air, and with 10 cells of the nitric acid battery, the spark is one-fifth of an inch in length, and brilliantly deflagrates gold and silver leaf.

This instrument, from the facility which it affords for uniting and disuniting the ends of the secondary wire, is well adapted for demonstrating the induction and reaction of electrical currents.

Numerous other forms of the electro-magnetic coil machine have been devised, principally for the medical administration of electricity; but as the principle is the same in all, it is unnecessary to describe them.

(202) **Ruhmkorff's Induction Coil.**—In the year 1842, MM. Masson and Breguet constructed a coil with which they obtained a spark between the terminals of the secondary coil *in vacuo*, and also ignited platinum wire; but from the imperfect way in which the wire was insulated, they could not obtain a sensible spark in free air, though they succeeded in charging a condenser. About the same time Mr. Hearder constructed a coil with which sparks could be obtained in air, and Leyden jars charged.

In 1851, M. Ruhmkorff brought the induction coil to far greater perfection than it had hitherto attained, by paying the greatest attention to the insulation of the secondary wire, which, after being covered with silk, was surrounded with a layer of gum lac, and the ends attached to glass columns fixed on the base-board of the instrument. He likewise increased considerably the length of the coil, diminishing at the same time its thickness, having found experimentally that the inductive effects of the apparatus are increased in proportion as the number of the spirals is augmented. As thus constructed, the instrument exhibited extraordinary effects: brilliant sparks were not only obtained at the points of disjunction, but also between the wire and a conducting body in communication with the earth, whilst in vacuo a brilliant and continuous stream of *stratified light* was produced. By interposing in the circuit of the primary or inducing wire a single condenser, as recommended by Fizeau, a further augmentation of power was obtained: the sparks in the free air were increased to nearly three-fourths of

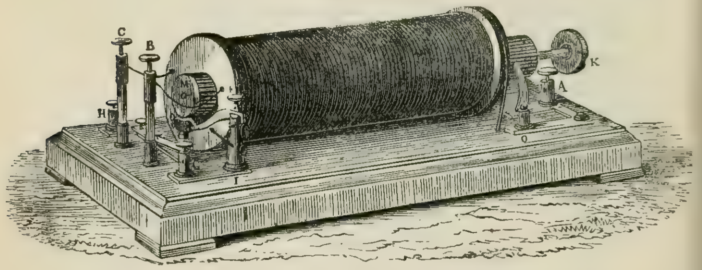
an inch in length, and were accompanied with a snapping noise, while the power of the shocks was exalted to such a degree as to be excruciating, and even dangerous.

Ruhmkorff's improved induction coil is shown in Fig. 281.

The bobbin is arranged horizontally; the core is of thin cardboard; and the ends are either of glass, or of well-varnished wood, or of gutta-percha. The primary coil is a well-insulated wire of about 0·078 inch in diameter; the secondary is a fine thin wire (No. 36 of commerce). The extremities of the latter pass through tubes of glass at the end of the bobbin, if the ends are made of wood, but simply through holes drilled in them if they are of glass or gutta-percha. In the figure the extremities of the thick coil are attached to the column I O, while the ends of the fine wire are inserted in the brass caps B C, insulated on glass columns. The wires leading from the voltaic battery are attached to the screws A B on either side of the commutator.

The Commutator.—This important part of the instrument, K L, is composed of a cylinder of ivory supported between two copper uprights. On

Fig. 281.

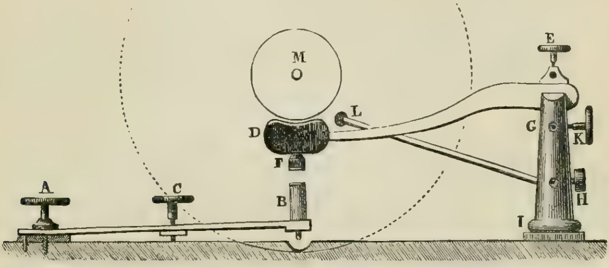


this cylinder are fixed by screws of unequal size two metallic plates A C, B D, made slightly convex. The largest screws, A and B, passing through the ivory, are inserted into the brass cylinders G and E; the smaller screws, C D, are merely sunk into the ivory; the copper uprights are in communication with the plates M and O of the inducing circuits. On turning the button P, suppose the plate B D to be brought into contact with the spring R in communication with the positive pole of the battery, the current will proceed in the direction of the arrows, entering the cylinder E along B, descending K L, and traversing the coil through M, will re-enter the commutator through O, and rising up H into the cylinder G, will proceed through the screw A, completing the circuit by A C in communication with the negative pole. If, on the other hand, the plate B D touch the spring in communication with the negative pole, it is easy to see that the direction of the current through the coil must be reversed.

The Interrupting Apparatus.—This is shown in Fig. 282. M is the fasciculus of iron wires in the axis of the coil; E D is a lever terminated by a plate of iron D, called the *hammer*; A B is a spring terminated by a massive piece of copper B, called the *anvil*. The screw A is connected with one of

the metallic strips which convey the current to the primary coil. The ends B and F, of the hammer and anvil, are tipped with finely-polished platinum. The end of the lever E D drops into a slit in the upper end of the column G I; one end of the primary coil enters the column at H. The operation of this interrupter is sufficiently obvious; as long as the anvil and hammer remain in contact the current is closed; but under the influence of the current the fasciculus of iron wires becomes magnetic, and the iron head of the hammer is attracted; the current is thus interrupted, but at the same moment the iron wires lose their magnetism, and the hammer falls again on the head

Fig. 282.



of the anvil; this act restores contact, the hammer is again attracted by the remagnetised iron, and thus the current is interrupted and renewed with a rapidity the greater as the distance between the hammer and anvil is less.

The Condenser.—This invention of Fizeau was adapted to his coil with great effect by Ruhmkorff. It consists of *two* sheets of tin-foil pasted on either side of a band of varnished silk, about 12 feet long, and folded between two other bands of the same silk, the whole being introduced into the interior of the wooden frame of the instrument. The coatings of this condenser are in contact with G H (Fig. 282).

The condenser, then, is a modification of the Leyden jar, but its functions are not clearly understood. According to Fizeau, it condenses and destroys by a *static* effect the electricity of tension or induction, which gives rise to an *extra* current in the induction wire and which reacts on the induced current in the secondary wire in a direction contrary to that of the voltaic current. The condenser, by absorbing the extra current, not only prevents its injurious action on the contact breaker, but becomes itself charged, one coating with positive and the other with negative electricity; these two electricities recombine immediately through the primary wire and battery, giving rise to a current contrary to that of the latter, the consequence of which is the instant demagnetisation of the iron core, and the production of an exceedingly intense wave of induced electricity of momentary duration. According to Faraday, the action of the condenser is to diminish the intensity

of the inducing current at the moment when it would otherwise produce injurious results. At the first moment of the birth of a current in the wire, *lateral* induction is brought about at the expense of the *direct* induction in the body of the wire, but as soon as the former has attained its maximum, the latter (that of the wire) becomes proportional to the intensity of the battery. Thus on connecting the two coatings of a Leyden phial by a long insulated wire, and presenting, near the points of its attachment to the armatures, the two ends of another wire so near that the resistance of the air shall be less than that of the wire, a great part of the discharge will take place across the air; but if the wire be in contact with one of the coatings of a condenser, then no spark will be perceived between the points; and it is for a similar reason that the spark of the interrupter in Ruhmkorff's apparatus is sensibly enfeebled.

The condenser does not increase the *quantity* of electricity set in motion in the secondary wire, as may be proved by the galvanometer, but it does vastly increase its intensity, as is demonstrated by its physiological effects, and by the length of the spark between the terminals.

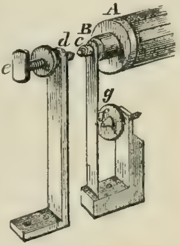
Great improvements have been made on the original induction coil of Ruhmkorff—by the inventor himself; by Hearder, Bentley, Apps, and Ladd, in this country; and by Ritchie, in America. These improvements have been based on—1. a special attention to the insulation and arrangement of the secondary coil; 2. the increase in the size and arrangement of the condenser; and 3. the method of breaking and renewing battery contact.

A good form of self-acting contact breaker for small coils is that devised by Ladd, which is constructed with the object of giving the operator the means of setting up a greater or less resistance to the attractive force exerted by the magnetic iron core.

This is accomplished by attaching the hammer to a stiff spring placed vertically (as shown in Fig. 283), where A is the disc of iron capping one end of the core; B the iron hammer of the contact breaker surmounting a stiff spring attached to a brass stand screwed to the base-board of the instrument; *c* is a little projecting nipple tipped with platinum; *d* a corresponding little disc of platinum soldered to the end of a screw which passes through the top of a brass pillar firmly screwed down to the base-board; the distance between *d* and *c* can be regulated with the greatest nicety by the thumb-screw *e*. Now when *c* and *d* are in contact, and the commutator is turned on, the battery current is circulating round the primary coil; the fasciculus of iron wires becomes magnetic; B is attracted to A, by which act *c* and *d* are separated; battery contact is hereby broken, and the effects of the induced current are obtained at the terminals of the secondary. Now by turning the screw *g* the point *f* attached to its axis

may be made to press with greater or less force on the spring supporting the hammer, thereby keeping *c* and *d* more or less firmly in contact, and necessitating a corresponding degree of magnetism of the fasciculus to part the platinum discs; when, however, this has been attained, contact with the battery is instantly broken, and the hammer is forced back with violence by the conjoint action of the spring and screw, *d* and *c* again come into contact, the iron core again becomes magnetic, A attracts B, and the battery current is stopped, *c* is again formed upon *d*, and so on.

Fig. 283.



Now a degree of pressure may be exerted on the spring support of B by the screw *g*, sufficiently great entirely to overcome the attractive force of A; under such circumstances the instrument is of course passive, but by relaxing to a certain degree, the magnetic power of the core just overcomes the antagonistic force of the spring, and then it is that the most powerful inductive effects are obtained, evidently because the fasciculus has received from the battery its maximum amount of magnetism, which it loses instantaneously by the interruption of the battery circuit, giving rise to a powerful wave of electricity in the secondary coil.

(203) **Ritchie's (American) Arrangement of Ruhmkorff's Induction Coil.**—One of the most powerful instruments for the development of the phenomena of induced secondary currents that has hitherto been constructed is that probably made by Ritchie, a philosophical instrument maker of Boston, U.S., for Mr. Gassiot (*Phil. Mag.*, vol. xv. p. 466). The primary wire (No. 9 gauge) is wound in three courses as a helix 150 feet in length; the interior bundle of wires, which are very carefully annealed, is 18 inches long and about $1\frac{3}{4}$ inch in diameter; the primary wire has a cover of gutta-percha one-tenth of an inch in thickness, passing through the basement to a plate of the same, to which it is united; over this gutta-percha a glass tube passes. The secondary helix is divided into three bundles, each 5 inches long, wound on cylinders of gutta-percha, one-tenth of an inch thick; the wire in the upper and lower is of No. 33 gauge, each 25,575 feet; the middle is of No. 32 gauge, 22,500 feet; forming a total length of 73,650 feet. The stratum of wire is perpendicular to the length of the helix, and the wire is covered with silk.

The *condenser* is made of varnished tissue-paper of three thicknesses between each stratum of tin-foil. There are three condensers with surfaces of about 20, 100, and 150 feet; by means of screws these can be used separately or combined.

The *contact* breaker is raised by means of a ratchet wheel turned by the hand, which acts on a spring, so that the platinum surfaces

touch freely. The upper platinum has a screw and binding nut; the hammer must not bear too heavily, and care must be taken to adjust the screws so that the ratchet wheel works well. When the handle is turned very slowly the contact with the primary current is prolonged, and the iron core becomes highly magnetised; the suddenness of the break instantaneously developes the entire force of the induced discharge, not only giving sparks of great length, but of a remarkably dense character, the main length of the discharge being surrounded by a sort of burr. If the velocity of the rotation be increased gradually, the discharge as gradually assumes the white luminous character of a long spark taken from the prime conductor of an electrical machine; while if the velocity of the rotation is still further increased, the luminous discharge in air will disappear, for there will then not be sufficient time between the make and break contact to magnetise the iron core on which the intensity of the induced discharge mainly depends.

When a single discharge is examined by Wheatstone's revolving mirror, it is seen to be elongated, but not divided; if a Leyden jar be introduced, the length of the spark is reduced, but it becomes exceedingly bright and dense, and when examined with the revolving mirror, it is resolved into two separated clearly defined sparks.

The maximum effect with the three coils, Gassiot considers, would probably be to produce a spark *fifteen inches long*, but he has not ventured to excite the coil to its greatest intensity. With five cells of the nitric acid battery (each platinum plate being 4 × 8 inches), he obtained from the three coils sparks or flashes *twelve and a quarter inches in length*; from two coils, of 10 inches; and from one coil, of 5 inches in length.

The method of coiling the secondary wire, beginning with the inner circle and gradually extending to the outer circumference (in the manner that seamen coil ropes on the deck), and continuing the next layer from the outer to the inner, and so on, repeating till the reel is completed, secures the coil from the risk of disruption, but it becomes liable for the discharge to pass from the internal terminal of the secondary to the primary, even when protected by a glass cover and thick gutta-percha.

Professor Callan uses iron wire for the secondary coil. He describes (*Phil. Mag.*, vol. xvii. p. 332) a coil which, though only 5 inches long, gives, with three cells of the cast-iron battery, each 4 inches square, sparks between the secondary terminals four and one-eighth inches long.

Ruhmkorff's large coils contain as much as 100,000 metres (=about 60 miles) of wire in the secondary coil; battery contact is broken and renewed by a pointed slip of platinum, which is

made to dip in and out of an amalgam of platinum and mercury, covered with alcohol, either by the hand or by an oscillating beam worked by a small electro-magnet. This magnificent electrical instrument, when excited by a single cell of Bunsen's battery, the carbon plates of which are 7×6 inches, gives sparks $3\frac{1}{4}$ inches in length; two cells give sparks $6\frac{1}{2}$ inches; three cells, sparks $10\frac{1}{2}$ inches; four cells, $12\frac{1}{4}$ inches; five cells, sparks 14 inches; six cells, sparks 15 inches; seven cells, sparks 16 inches. Beyond this it is not safe to go for fear of injury to the instrument, though with eight cells sparks or flashes upwards of 19 inches in length have been obtained.

Mr. Ladd constructs coils with between 6 and 7 miles of secondary wire which, when excited by five cells of Grove's nitric acid battery, platinum plates $5\frac{1}{2} \times 4$ inches, give sparks between 8 and 9 inches in length. These lengths he has since exceeded.

(204) **Apps's Inductorium.**—The greatest improvements which have been made of late years have been accomplished by Mr. Apps, of London, who has succeeded in the production of induction coils giving longer sparks than any hitherto made. The large inductorium made for the Polytechnic gave a 29-inch spark, but with a less machine manufactured for Mr. Spottiswoode a spark of 42 inches has been obtained. In machines manufactured by Mr. Apps he has succeeded in obtaining sparks longer than the coils themselves.

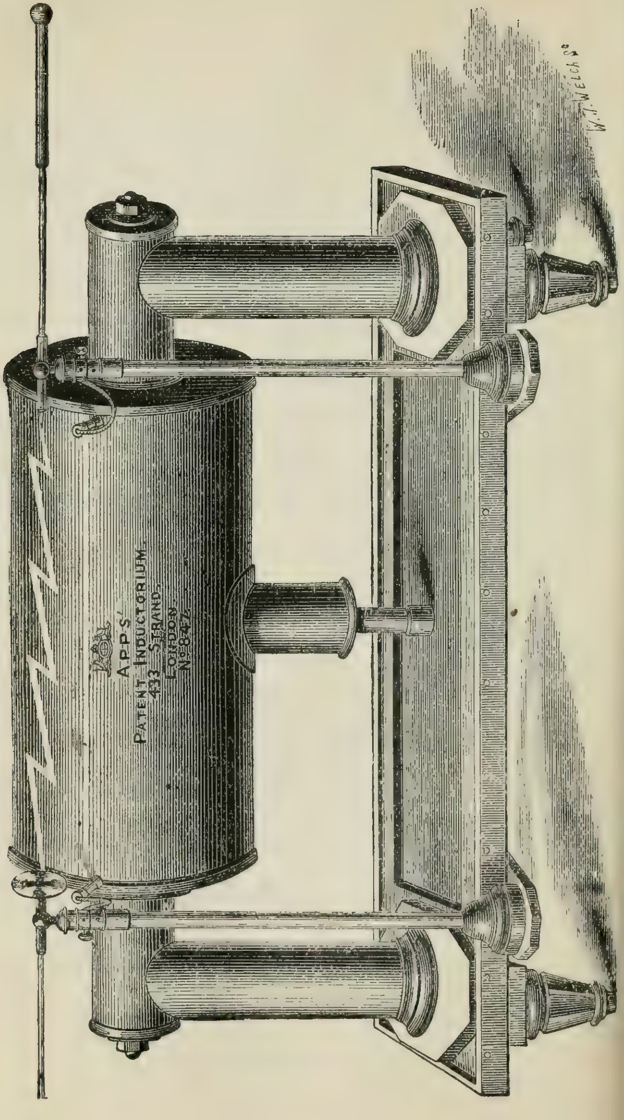
The Figs. 284 and 285 give a front view of the inductorium, and a section of the arrangement of the coils. The following description has been furnished by Mr. William Spottiswoode, F.R.S., himself:—

'Although I have not as yet many experimental results sufficiently complete for communication to your Magazine,[1] I still think that the construction of an induction coil capable of giving a spark 42 inches in length is an instrumental feat deserving of record in the annals of science. I therefore venture to submit the particulars of this coil, recently completed for me by Mr. Apps, of 433 Strand, to whose skill and perseverance the success of the undertaking is due.

'The general appearance of the instrument is represented in the following figure, by which it is seen that the coil is supported by two massive pillars of wood sheathed with gutta-percha, and filled in towards their upper extremities with paraffine wax. Besides these two main supports, a third, capable of being raised or lowered by means of a screw, is placed in the centre, in order to prevent any bending of the great superincumbent mass. The whole stands on a mahogany frame resting on castors.

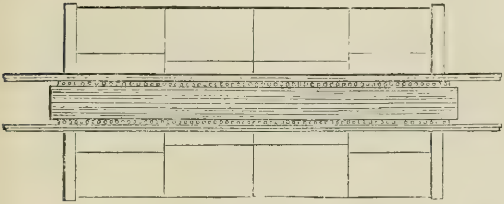
[1] *Philosophical Magazine.*

Fig. 284.


APPS'
PATENT INDUCTORIUM
433 STRAND
LONDON
No 847
W. J. WELCH Sc

'The coil is furnished with two primaries, either of which may be used at pleasure. Either may be replaced by the other by two men in the course of a few minutes. The one to be used for long sparks, and indeed for most experiments, has a core consisting of a bundle of iron wires each 0·032 inch thick, and forming together a solid cylinder 44 inches in length and 3·5625 inches in diameter. Its weight is 67 lbs. The copper wire used in this primary is 660 yards in length, 0·096 inch in diameter, has a conductivity of 93 per cent., and offers a total resistance of 2·8 ohms. It contains 1,344 turns wound singly in 6 layers, has a total length of 42 inches, with an internal diameter of 3·75 inches and an external of 4·75 inches. The total weight of this wire is 55 lbs.

Fig. 285.



'The other primary, which is intended to be used with batteries of greater surface—*e.g.* for the production of short thick sparks, or for spectroscopic purposes—has a core of iron wires 0·032 inch thick, forming a solid cylinder 44 inches long and 3·8125 in diameter. The weight of this core is 92 lbs. The copper wire is similar to that in the primary first described; but it consists of 504 yards wound in double strand, forming three pairs of layers, whose resistances are 0·181, 0·211, 0·231 ohms respectively. Its length is 42 inches, its external diameter 5·5, and its internal 4 inches. Its weight is 84 lbs. By a somewhat novel arrangement, these three layers may be used either in series as a wire of 0·192 inch thickness, or coupled together in threes as one of 0·576 inch thickness. It should, however, be added that, owing to the enormous strength of current which this is capable of carrying, and to the highly insulated secondary coil being possibly overcharged so as to fuse the wire, this larger primary is best adapted for use with secondary condensers of large surface, for spectrum analysis, and for experiments with vacuum-tubes in which it is desirable to produce a great volume of light of high intensity as well as of long duration at a single discharge. The alternate discharges and flaming sparks can also be best produced by this primary. It has been used for high-

tension sparks to 34 inches in air, the battery being 10 cells of Grove's with platinum plates $6\frac{1}{4} \times 3$ inches. Great facilities for the use of different sets of batteries are afforded by the division of this primary into three separate circuits, to be used together or separately; and by a suitable arrangement of automatic contact-breakers, the primary currents may be made to follow in a certain order as to time, duration, and strength, with effects which, when observed in the revolving mirror, will doubtless lead to important results in the study of striæ in vacuum-tubes.

'We now come to the secondary, which consists of no less than 280 miles of wire, forming a cylinder 37·5 inches in length, 20 inches in external, and 9·5 inches in internal diameter. Its conductivity is 94 per cent.; and its total resistance is equal to 110,200 ohms. The whole is wound in four sections, the diameter of the wire used for the two central sections being 0·0095 inch, and those of the two external being 0·0115 inch and 0·0110 inch respectively. The object of the increased thickness towards the extremities of the coil was to provide for the accumulated charge which that portion of the wire has to carry.

'Each of these sections was wound in flat disks; and the average number of layers in each disk is about 200, varying, however, with the different sizes of wire, &c. The total number of turns in the secondary is 341,850.

'The great length of the wire necessary can be easily understood from the fact that near the exterior diameter of the coil a single turn exceeds 5 ft. in length. The spark, it is believed, is due to the number of turns of wire, rather than to its length, suitable insulation being preserved throughout the entire length. In order to ensure success, the layers were carefully tested separately and then in sets, and the results noted for comparison. In this way it was hoped that step by step safe progress would be made. As an extreme test, as many as 70 cells of Grove's have been used, with no damage whatever to the insulation.

'The condenser required for this coil proves to be much smaller than might at first have been expected. After a variety of experiments, it appeared that the most suitable size is that usually employed, by the same maker, with a 10-inch-spark coil—viz. 126 sheets of tinfoil $18 \times 8·25$ inches in surface, separated by two thicknesses of varnished paper, the two thicknesses measuring 0·011 inch. The whole contains 252 sheets of paper 19×9 inches in surface. I hope, at some future opportunity, to make further experiments with other condensers.

'Using the smaller primary, this coil gave, with 5 quart cells of Grove, a spark of 28 inches, with 10 similar cells one of 35 inches,

and with 30 such cells one of 37·5 inches and subsequently one of 42 inches. As these sparks were obtained without difficulty, it appears not improbable that if the insulation of the ends of the secondary were carried further than at present, a still longer spark might be obtained. But special adaptations would be required for such an experiment, the spark of 42 inches already so much exceeding the length of the secondary coil.

'When the discharging points are placed about an inch apart, a flowing discharge is obtained both at making and at breaking the primary circuit. The sound which accompanies this discharge implies that it is intermittent, the time- and current-spaces of which have not as yet been determined.

'With a 28-inch spark, produced by 5 quart cells, a block of flint glass 3 inches in thickness was in some instances pierced, in others both pierced and fractured, the fractured pieces being invariably flint glass. If we may estimate from this result, the 42-inch spark would be capable of piercing a block 6 inches in thickness.'

When used for vacuum-tubes this coil gives illumination of extreme brilliancy and very long duration; with 20 or 30 cells and a slow-working mercury break, giving, say, 80 sparks per minute, the striæ last long enough for their forward and backward motion to be perceived directly by the unassisted eye. The appearance of the striæ when observed in a revolving mirror (as described in the *Proceedings of the Royal Society*, vol. xxv. p. 73) was unprecedentedly vivid, and this even when only two or three cells were employed.—*Phil. Mag.*, vol. 3, No. 15.

(205) **Phenomena of the Induced Current.**—1. *The Spark in Air.*—Taken between two wires of sufficient thickness, it appears under the form of a bundle of three or four darts of fire more or less curved; between larger surfaces the sparks pass at longer intervals, but with greater noise and energy. When the interruptions of the primary are slow, the sparks are longer than when they are rapid, *time* being required for the development of induction. It must be observed that although when the poles of the secondary coil are connected by a metallic wire, or by a good conducting liquid, there are two currents moving alternately in opposite directions, yet when the poles are separated by a thin stratum of air, *one* only of these two currents or waves is brought into action, that, namely, due to the breaking of the voltaic current; the other, that produced by closing the current, is stopped off from the secondary wire being expended in the primary wire itself. The secondary wire gives then a series of intermitting currents, all of which have a common direction.

If the spark be attentively watched in the dark, it is seen to be surrounded with a sort of yellow-green atmosphere of greater or less thickness, according to the force of the battery. It is generally of an ovoid form, and seems to be collected principally round the negative pole. When a steady current of air is thrown upon the spark taken between two metallic wires, the luminous atmosphere becomes expanded into a large mass of irregular violet-coloured flame, surrounded by bundles of rays, the spark itself not appearing to undergo any variation.

If the spark be passed through a glass tube by means of wires hermetically sealed into its sides, and the ends about one-tenth of an inch apart, *red vapours* are formed in from ten minutes to half an hour, proving that the oxygen and nitrogen have entered into chemical combination. Becquerel and Frémy have proposed this experiment as a test for nitrogen.

In condensed air the spark is short, and more collected, as is the case with ordinary electricity. In rarefied air, on the contrary, it receives a wonderful development, but is less intense in light. In *hydrogen* the spark is feeble, and very red; in *carbonic acid*, it is vivid and white. *Ozone* may be produced by the induction spark, either directly or indirectly. In the former case, the spark is taken between two wires sealed into a tube filled with pure dry oxygen; the sparks must succeed each other slowly and gently.

(206) **Decomposition of Gaseous Compounds.**—When the induction spark is sent through ammoniacal gas, it exhibits a violet light surrounded with a blue edge; the gas soon undergoes decomposition, the original volume being doubled, the spark then exhibits the pure violet light characteristic of hydrogen, and water projected into the tube produces no diminution of volume. The coil thus becomes a useful instrument for demonstrating the composition of this alkaline gas.

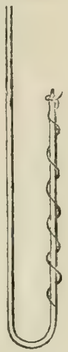
For the introduction of the spark current through this and other gaseous compounds, the simple apparatus shown in Fig. 286 was contrived by Buff and Hoffmann.

A fine platinum wire is fused into the shorter limb of a thin U-shaped glass tube, and filed off so as scarcely to project beyond the glass. At a distance of a few millimetres from the platinum pole thus obtained, the loop of a second platinum wire is thrown over the tube, and the wire wound round the tube until it nearly reaches the bend. The tube is then filled with mercury, and the shorter limb introduced into the gas-tube containing the gas to be operated upon, inverted over mercury in a deep cylinder trough. The pole wires of the induction coil being now introduced, the one into the open end of the U-tube filled with mercury, and the other into the mercury of the cylinder trough, the spark current may be established or interrupted

at will, by either depressing the U-tube until the outer platinum wire reaches the surface of the mercury, or by lifting it so as to break contact.

2. *The Spark in Liquids.*—In all good conducting liquids there is of course no spark; but in those liquids which conduct either imperfectly, or not at all, crackling sparks are obtained. In *oil* the sparks are greenish white, in *alcohol* they are red and crepitating; brilliant sparks are obtained in *turpentine* and *bisulphide of carbon.* If some oil be poured on the surface of water in a glass vessel, and one of the wires covered with gutta-percha introduced beneath the water, and the other immersed in the oil within striking distance, strong crepitating sparks are obtained, and hydrogen gas is liberated, which burns on the surface of the liquid. Between a pair of *guarded* platinum points a continuous light may be kept up in acidulated water, or in a solution of sulphate of copper.

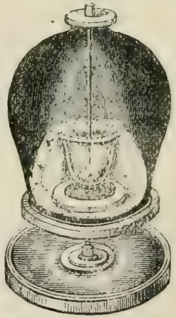
Fig. 286.



3. *The Spark in Rarefied Air and Gases.*—When the discharge from the induction coil is made to pass through highly rarefied air, the phenomena of auroral light (p. 100) are produced in a beautiful and varied manner across long intervals. One of the most beautiful experiments that can be made with the secondary current is probably the following, thus described by Mr. Gassiot, and called the *Electrical Cascade* (*Phil. Mag.*, vol. vii. p. 854):—

Two-thirds of a beaker, $4\frac{1}{2}$ inches deep by 2 inches wide, are coated with tin-foil, leaving 1·5 inch of the upper part uncoated. On the plate of an air-pump is placed a glass plate, and on it the beaker, covering the whole with an open-mouth glass receiver, on which is placed a glass plate having a thick wire passing through a collar of leathers; the portion of the wire within the receiver is covered with a glass tube. One end of the secondary coil is attached to this wire, and the other to the plate of the pump. As the vacuum improves, the effect is truly surprising: at first a faint clear blue light appears to proceed from the lower part of the beaker to the plate; this gradually becomes brighter until by slow degrees it rises, increasing in brilliancy, until it arrives at that part which is opposite or in a line with the inner coating the whole being intensely illuminated. A discharge then commences from the inside of the beaker to the plate of the pump in minute but diffused streams of blue light; continuing the exhaustion, at last a discharge takes place in the form of an

Fig. 287.



undivided continuous stream, overlapping the vessel as if the electric fluid were itself a material body running over. If the position of the beaker be reversed by placing the open part on the plate of the air-pump, and the upper wire is either in contact with or within an inch of the outside of the vessel, streams of blue lambent flame appear to pour down the sides of the plate, while a continuous discharge takes place from the inside coating. The arrangement of this experiment is shown in Fig. 287.

If a tube, from 3 to 7 feet long and from $1\frac{1}{2}$ to 2 inches in diameter, be connected by wires at each end with the terminals of the secondary coil, and the air removed by an air-pump, as the exhaustion proceeds a splendid auroral light fills the tube with coruscations, and as the vacuum gets more perfect a broad crimson riband is obtained, extending throughout the entire length of the tube. If a small quantity of air be then admitted, the riband disappears and the coruscations return; but these gradually die out as the air enters. A few strokes of the pump, however, bring them back again, and thus, by increasing or diminishing the density of the air, the appearance of the discharge in the tube may be made to undergo corresponding variations.

(207) **Stratifications in Electrical Discharges in Torricellian and other Vacua.**—Mr. Grove, in his investigations to determine the electro-calorific effects due to the polar reactions of induced currents on metallic plates, made, among other experiments, the following:—A piece of carefully dried phosphorus was placed in a little metallic cap and covered with a receiver having a cap and wire; on making a good vacuum, instead of a simple diffused light, he obtained a light completely stratified—that is to say, divided transversely to the direction of the jet by a multitude of very straight and mobile black bands. Similar phenomena were subsequently noticed by Ruhmkorff in an alcohol vacuum—viz. magnificent vibrating stratifications in the middle of the red light issuing from the positive pole. They were also studied by M. Quet (*Comptes Rendus*, Dec. 1852).

When the poles of the secondary are about 3 or 4 inches apart in a good vacuum produced in the electric egg (Fig. 288) two distinct lights are produced, differing in colour, form, and position; that round the negative ball and wire is blue, it envelopes it regularly; that round the positive is fire-red, it adheres to one side, and stretches across towards the negative. On close examination, this double light is seen to have a singular constitution; it is stratified, being composed of a series of brilliant bands, separated from each other by dark bands. These bands are well observed in vacua of *wood spirit*, *spirit of turpentine*, *alcohol*, *naphtha*, and *bichloride of tin*, and the vacuum must be as perfect as the best air-pump can

make it. The appearance is then that of a pile of electric light. In the red light the brilliant bands approaching nearest the negative ball have the form of capsules, the concave part being turned towards the ball; their position and figure are sensibly fixed. The extreme capsule does not touch the violet light of the negative pole, being separated from it by a dark band, greater or less according to the nature and perfection of the vacuum, that with spirits of turpentine giving the greatest.

Fig. 288.

Fig. 290.

Fig. 289.

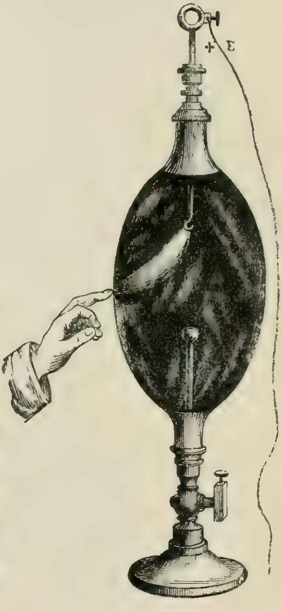


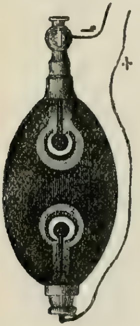
Fig. 288 presents an accurate representation of this singularly beautiful phenomenon.

A light, though less red and brilliant, may be obtained from one pole of the secondary wire only, that of the exterior end of the coil which possesses electricity of the greatest tension; and, if the vacuum be very good, this light may be made to bifurcate by placing the finger against the outside of the glass, as shown in Fig. 289.

If a bar of soft iron, surrounded with a coil of insulated copper wire, be fixed into the cap of the electric egg (Fig. 290), and the latter be then exhausted, a splendid band of purple light is produced, which commences rotating round the iron rod the moment the latter is converted into an electro-magnet by sending the current from a small voltaic battery through its surrounding coil. On changing the direction of the induced current, the direction of the rotation changes also. The electric light in this beautiful experiment takes the place of the conducting wire in Faraday's experiment (Fig. 222, p. 282).

M. Quet found that, when a galvanometer was interposed in the circuit, no current was indicated as passing through the electric egg till the exhaustion was tolerably good, and the light continuous; the needle then became permanently deflected. The first light that appeared was the *red* round the positive ball, but it was not till the exhaustion became very perfect that the *blue* light became well developed and extended round the negative wire.

Fig. 291.



If a considerable resistance be introduced into the induced circuit, or if the two currents be made to circulate in opposite directions through the receiver, the red light disappears from the positive pole, giving place to a blue light; the positive and negative lights are now the same, the appearance of the egg being as represented in Fig. 291.

(208) **Investigations of Gassiot.**—The phenomena of the stratification in electrical discharges, as observed in Torricellian and other vacua, have been minutely studied by Gassiot (*Phil. Trans.*, March 4, 1858; the '*Bakerian Lecture*,' and *Phil. Trans.*, Jan. 13, 1859). When the discharge from the induction coil is transmitted through a Torricellian vacuum, the cylinder is beautifully illuminated with a dense phosphorescent light, filling the entire vacuum, the intensity of the light depending on the energy of the battery. This light has generally been observed to be without stratification, but by employing great care in the construction of the vacua, and using a single cell of Grove's battery, Gassiot obtained distinct stratification, extending from the positive wire to the dark space, while the usual blue flame surrounding the intense red, which has the appearance of red heat, was visible on the negative wire.

A good stratification is shown in Fig. 292, the tube being as

perfect a Torricellian vacuum as could be made with pure and carefully boiled mercury, and Fig. 293 shows the wavy line dis-

Fig. 292.

charge in a similar tube in which a slight trace of moisture was present; no stratifications are here visible, though they are immediately produced by condensing the moisture by plunging the tube into a freezing mixture. In Torricellian vacua obtained by Welsh's

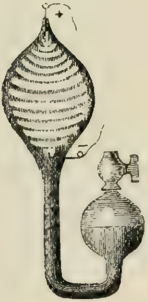
Fig. 293.

process, the mercury not being boiled (*Phil. Trans.*, vol. cxlvi. p. 507), the phenomena of the stratified discharge could be examined with ease and care.

Figs. 294 and 295 are faint representations of the beautiful appearances of the stratifications as obtained in pear-shaped vessels.

Fig. 294.

Fig. 295



That shown in Fig. 293 is 3 inches in internal diameter, the wires being 5 inches apart from point to point. The vessel was filled

with pure mercury and boiled; it was afterwards exhausted by the air-pump. If the mercury be permitted to ascend, immediately it covers the negative wire the stratifications disappear and the interior of the globe is filled with bluish light; a bright spot of light is visible on the end of the positive wire, and the negative mercury is covered with a white phosphorescent film about one-eighth of an inch in thickness.

The egg-shaped vessel represented in Fig. 294 is 25 inches long, the globular part being 18 inches in length and 7 inches in diameter; the wires *a b* are 22 inches apart, and caustic potash is placed in the narrow end. It is charged with carbonic acid, and then exhausted. On heating the caustic potash with a spirit-lamp, the discharge assumes the character of large and distinct clouds, clearly and separately defined, and extending to the entire diameter of the vessel; these clouds are strongly affected by induction as the hand approaches the globe, presenting a very striking appearance.

No signs of any discharge can be observed in the *vacuum* on making contact when the primary current is excited by a single cell, but evidence of action in the secondary coil can be detected by the galvanometer, and also in the following manner:—

Let the ends of the platinum wires attached to the terminals of the secondary coil rest on a piece of bibulous paper moistened with a solution of iodide of potassium, complete the circuit of the commutator, and then remove the paper, *iodine* will be evolved from one terminal.

Make contact with the moistened paper, keeping the primary circuit complete; remove the paper, no trace of iodine is perceptible, proving that in this state there is no current in the secondary wire. Again, make contact with the moistened paper and the platinum wire, break the circuit with the commutator, and iodine will be immediately evolved at the opposite terminal in much larger quantity than in the former case.

In order to ascertain whether the stratifications in the positive discharge arise from *interference*, Gassiot caused the discharges from two separate coils to intermingle with each other; and he found that, whether they were made in the same direction or opposed to each other, the separate stratifications from the discharge of each coil remained visible, although producing a degree of confusion from their interposition. The positive division of the discharge is of greater intensity, and consequently of much greater length, than the negative. Gassiot has obtained the stratifications in a tube 5 feet 8 inches in length; he found also that the stratifications are very powerfully affected by the magnet. When the discharge is made from wire to wire, if a horseshoe magnet be placed along the tube so as alternately to present the poles to different contiguous

positions of the discharge, it will assume the form of ~ in consequence of its tendency to rotate round the poles in opposite directions as the magnet in this position is moved up and down the side of the tube.

When the discharge was first made in the pear-shaped apparatus (Fig. 295), the mercury being negative, and allowed to enter the vessel till about two inches from the positive wire, the discharge formed nearly a straight line; in this position, when the pole of a powerful electro-magnet was placed close to the glass vessel, the discharge was deflected across the pole at right angles, the discharge being from the positive wire to the negative mercury; if the pole presented was north, the discharge was deflected to the right when looking from the magnet to the discharge, carrying with it the red spot in a direct line across the mercury.

Two Distinct Forms of Stratified Electrical Discharge.—Fig. 296 represents a vacuum tube 38 inches long, the wires,

Fig. 296.

a b, 32 inches apart; *c c′* are movable coatings of tin-foil two inches long, wrapped round the tube. When the discharges from an induction coil are made from wire to wire, clear well-defined striæ are obtained; and if the tube be placed in a horizontal position over the pole of a magnet, the stratifications evince a tendency to rotate as a whole, in accordance with the known laws of electromagnetic rotation; but when the discharge is from coating to coating, the stratifications have no longer a tendency to rotate as a whole, but are *divided*. If the tube be now placed *between* the poles of a powerful electromagnet, one set of stratifications are repelled from and the other attracted towards or within the bent portion of the magnet; and when the tube is placed on the north pole, the divided stratifications arrange themselves on each side of the tube, changing their respective positions when placed on the south pole, but in all cases each set of stratifications are concave in opposite directions.

Gassiot designates the first form of stratified discharge the *direct*, and the latter the *induced* discharge.

Influence of Temperature on the Stratified Discharge.—The following experiment is described by Mr. Gassiot:—

Fig. 297 represents a Torricellian vacuum tube, 22 inches long and $1\frac{3}{4}$ inch internal diameter; the wires, *a b*, are 19 inches apart; sufficient mer-

cury remains in the tube to cover the lower wire, and in this manner one terminal is a wire of platinum, and the other a surface of mercury; *c* is a glass vessel to contain a freezing bath, composed of ether and solid carbonic acid. When this tube is suspended by a string, its lower end not being immersed in the freezing mixture, the induction coil, excited by a single cell of the nitric acid battery, gives clear, distinct, large cloudlike discharges, leaving a dark band 14 or 15 inches in length. When a magnet is presented a little above the surface of the mercury, a brilliant blue phosphorescent discharge proceeds from the upper part of the negative terminal (*b*), while at the same time cloudlike stratifications from the positive wire are brought down the tube. This phosphorescent blue discharge can, by manipulation, be expanded or contracted by the magnet in a remarkable manner. If the lower end of the tube be immersed in the freezing bath, as shown in the figure, when the temperature is reduced to $-85°$ Fah., discharges from the induction coil being made, the stratifications are no longer visible, but a small luminous spot remains at the end of the positive terminal.

Fig. 297.

On presenting the north pole of a magnet on one side of this luminous spot, or the south pole on the other, another luminous spot was visible. On removing the tube from the ether bath, the mercury gradually liquefied, the temperature rose, and at $+20°$ Fah. the stratifications reappeared.

When, instead of cooling the mercury in the vacuum tube, it was gradually raised to its boiling point ($+600°$ Fah.), all traces of stratification were likewise destroyed, but in this case the discharge passed along the mercury as it condensed in the cooler part of the tube.

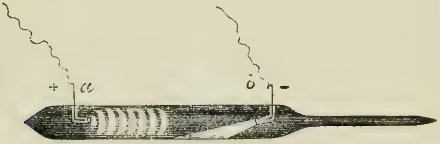
(209) **Non-conducting Power of a Perfect Vacuum.**—When a vacuum tube is in a state to show the stratified discharge, it is so good a conductor that sparks from the outer terminal of the induction coil will pass to one of its wires (the other being attached to the inner terminal) one inch in length through air; but Gassiot obtained carbonic acid vacua so perfect that no signs of luminous discharge could be observed through the tube; in this state it was a more perfect insulator than air itself, and no sparks could be obtained from the outer terminal.

If two vacuum tubes which conduct are attached one to the inner and the other to the outer terminal of an induction coil without being otherwise connected with each other, a reciprocating dis-

charge will take place in each, that from the outer being by far the more vivid ; if the circuit be now completed, either by a wire or by a tube which conducts, the stratifications in each tube become clear and distinct, the dark discharges becoming as visible as if the circuit with the coil had been completed by a single tube; but if the circuit be completed by a perfect carbonic acid vacuum tube, the discharges in the two conducting tubes attached to the coil are reciprocating, while in that of the non-conducting tube no luminous appearance is perceptible.

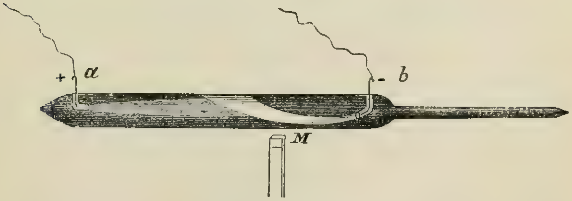
(210) **Condition of Discharge at the Negative Terminal.** —If the negative wire in a vacuum tube be protected by glass tubing open at the end about one-eighth of an inch beyond the point of the wire in the tube, no stratifications can be observed in

Fig. 298.



the discharge, which, in such cases, merely exhibits a luminous glow; if now the intensity be reduced, stratifications towards the positive wire are obtained, and if the negative wire and tubing are a little inclined, the discharge from the negative wire will impinge against the side of the vacuum tube, brilliantly illuminating the spot on which it strikes; if a magnet be presented, the spot will be contracted with one pole, and with the other the discharge will be bent in a manner so that its extreme portion

Fig. 299.



will itself impinge on the other side of the tube. If the experiment be made by reducing the intensity of the discharge, so that stratifications from the positive terminal are observable, these stratifications vanish as the discharge, which apparently proceeds

from the negative terminal, is forced by the magnet along the tube.

In this experiment there is the appearance of a direction of a force emanating from the negative terminal, as well as one from the positive. The appearances in the tube in these experiments are represented in Figs. 298 and 299.

The different phases of the electrical discharge in vacua rendered progressively more and more perfect, are well observed in tubes that have been filled with carbonic acid, exhausted, and the small residue of gas gradually absorbed by caustic potash. The first discharge is that of a wave passing from wire to wire; it next becomes a luminous glow, filling the tube, and showing narrow stratifications commencing at the positive wire, the negative being surrounded by a blue glow. As the vacuum improves, the narrow stratifications extend throughout the discharge to about one inch of the negative wire, where they terminate abruptly in a dark space, the negative wire becoming intensely red; the stratifications then become more distinct and separated, and the dark space often extends in a tube of 20 inches in length to 6 or 8 inches; they next assume a conical form, and sometimes disappear altogether, the tube being filled with a faint luminosity; finally, when the absorption of the carbonic acid is complete, all signs of luminosity disappear, proving the non-transferring condition of a perfect vacuum.

Glass tubes containing highly rarefied gases and vapours, and of various forms and sizes, are now constructed with wonderful ingenuity, and may be procured at many philosophical instrument-makers. The light produced on passing the induced current through many of these tubes is of the most beautiful and varied character.

(211) **What is the Physical Cause of the Stratifications?** —The following theory was advanced by Grove:—When the battery contact is broken, there is generated the well-known induced current in the secondary wire in the same direction as the original battery current, to which secondary current the brilliant effects of the coil are due; but in addition to this current in the secondary wire there is also a secondary current in the primary wire flowing in the same direction, the inductive spark at the moment following the disruption of contact completing the circuit of the primary, and thus allowing the secondary current to pass. This secondary current in the primary wire produces in its turn another secondary, or what may be termed a tertiary, current in the secondary wire in an opposite direction to the secondary current. There are thus almost synchronously two currents in

opposite directions in the secondary wire; these, by causing a conflict or irregular action on the rarefied medium, would give rise to waves or pulsations which might account for the stratified appearance. It is obvious that the secondary current must be more powerful than the tertiary. Now supposing an obstacle or resistance placed in the secondary current which the secondary current can overcome, but which the tertiary current cannot, we ought by theory to get no striæ. If an interruption be made in the secondary current in addition to that formed by the rarefied medium, and this interruption be made of the full extent which the spark will pass, there are as a general rule no striæ in the rarefied media, while the same vacuum tube shows the striæ well if there be no such break or interruption. Thus on passing the discharge through a large vacuum cylinder (16 inches by 4 inches), and using a micrometer-electrometer, numerous broad and perfectly distinct bands were obtained when the points of the micrometer were in contact; but when they were separated to the fullest extent that would allow sparks to pass, not the slightest symptoms of bands or striæ were perceptible, the whole cylinder being filled with an uniform lambent flame.

With a spark from the prime conductor of an electrical machine, the striæ do not appear in tubes which show them well with the induction coil. This, Grove thinks, is in favour of his theory; but, without regarding that as conclusive, or as an approved *rationale*, it seems demonstrated by the experiments above described that the identical vacuum tubes which show the striæ with certain modes of producing the discharge do not show them with other modes, and that, therefore, the striæ are not a necessary condition of the discharge itself in highly attenuated media, but depend upon the mode of its production.

The experiments described by Gassiot (*Phil. Trans.*, 1859) are not in accordance with Grove's view. He found that when a Leyden discharge was sent through a vacuum tube, stratifications as clear and distinct as those from the induction coil may be obtained by reducing the intensity by the introduction into the circuit of a piece of wet string; he hence inferred that in Grove's experiment the absence of striæ, when the circuit was interrupted, was due to the heightened intensity of the discharge. He repeated Grove's experiment with the large cylinder, and obtained a similar result; the stratifications were entirely destroyed when the secondary current was interrupted, but they were restored when a second interruption was made in the circuit, and this closed by a wet string; in this case it is evident that the appearance of the striæ does not depend upon the conflict of secondary and tertiary cur-

rents, but upon the manner in which the discharge passes. Gassiot found, moreover, that, when by means of an interrupted discharge the stratifications are destroyed, they are reproduced in a carbonic acid vacuum tube when heat is applied to the caustic potassa; here the increased resistance arises from the greater density of the matter formed in the tube: and this experiment is in favour of his view, viz. 'that the stratifications arise from the effect due to impulses or pulsations of a force acting on highly attenuated matter.'

(212) **Experiments to Ascertain the Cause of Stratification in Electrical Discharges in Vacuo.**—Some interesting experiments on this subject were made in 1875 (see *Proceedings of the Royal Society*, No. 160) by Messrs. Warren de la Rue, Hugo Müller, and William Spottiswoode, with the aid of a new and powerful battery of Mr. de la Rue's, and the experiments are thus described :—'Some results obtained in working with a chloride of silver battery of 1,080 cells in connection with vacuum tubes have been recently repeated. The battery used up till now consists of 1,080 cells, each being formed of a glass tube 6 inches (15·23 centim.) long and $\frac{3}{4}$ of an inch (1·9 centim.) internal diameter; each is closed with a vulcanised rubber stopper (cork), perforated eccentrically to permit the insertion of a zinc rod, carefully amalgamated, $\frac{3}{16}$ of an inch (0·48 centim.) diameter and 4·5 inches (11·43 centim.) long. The other element consists of a flattened silver wire passing by the side of the cork to the bottom of the tube, and covered at the upper part, above the chloride of silver and until it passes the stopper, with thin sheet gutta-percha for insulation, and to protect it from the action of the sulphur in the vulcanised corks; these wires are $\frac{1}{16}$ of an inch (0·16 centim.) broad and 8 inches (20·32 centim.) long. In the bottom of the tube is placed 225·25 grains (14·56 grms.) chloride of silver in powder; this constitutes the electrolyte; above the chloride of silver is formed a solution of common salt, containing 25 grammes chloride of sodium to 1 litre (1·752 grains to 1 gallon) of water to within about 1 inch (2·54 centim.) of the cork. The connection between adjoining cells is made by passing a short piece of india-rubber tube over the zinc rod of one cell, and drawing the silver wire of the next cell through it, so as to press against the zinc.

'The closing of the cells by means of a cork prevents the evaporation of water, and not only avoids this serious inconvenience but also contributes to the effectiveness of the insulation. The tubes are grouped in twenties in a sort of test-tube rack, having four short ebonite feet, and the whole placed in a cabinet 2 ft. 7 in.

(78·74 centim.) high, 2 ft. 7 in. wide, and 2 ft. 7 in. deep, the top being covered with ebonite to facilitate working with the apparatus, which is thus placed on it as an insulated table.

'The electromotive force of the battery, as compared with a Daniell's (gravity) battery, was found to be as 1·03 to 1,[1] its internal resistance 7 ohms per cell, and it evolved 0·214 cub. centim. (0·0131 cub. inches) mixed gas per minute when passed through a mixture of 1 volume of sulphuric acid and 8 volumes of water in a voltameter having a resistance of 11 ohms. The striking-distance in air of 1,080 elements between copper wire terminals, one turned to a point, the other to a flat surface, is $\frac{1}{263}$ inch (0·096 millim.) to $\frac{1}{250}$ inch (0·1 millim.) The greatest distance through which the battery-current would pass continuously *in vacuo* was 12 inches (30·48 centim.) between the terminals in a carbonic acid residual vacuum. This battery has been working since the early part of November 1874, with, practically, a constant electromotive force.

'Besides 2,000 more cells like those just described, we are putting together 2,000 cells, with the chloride of silver in the form of rods, which are cast on the flattened silver wires, as in a battery described by De la Rue and Müller,[2] but in other respects similar to the battery above described, the glass tubes being, however, somewhat larger in diameter; the rods of chloride of silver are enclosed in tubes open at the top and bottom, and formed of vegetable parchment, the object of these vegetable parchment cases being to prevent contact between the zinc and chloride of silver rods. The internal resistance of batteries so constructed is only from 2 to 3 ohms per cell, according to the distance of the zinc and chloride of silver rods, and they evolve from 3 to 4·5 cub. centim. (0·18 to 0·27 cub. inch) per minute, in a voltameter having a resistance of 11 ohms. Their action is remarkably constant.

'For the experiments detailed below, vacuum tubes were generally used of about 1½ to 2 inches (3·8 to 5 centim.) in diameter, and from 6 to 8 inches (15·24 to 20·32 centim.) long; also prolate spheroidal vessels 6 inches by 3 inches (15·24 by 7·62 centim.) The terminals are of various forms, and from 4 inches to 6 inches (10·16 to 15·24 centim.) apart, and made of aluminium, and occasionally of magnesium, and of palladium, the latter showing some curious phenomena with a hydrogen residual vacuum, which will be described in a future paper. A tube which has given the

[1] 'Compared with a Daniell's battery, in which the zinc is immersed in dilute sulphuric acid in a porous cell, its electromotive force is about 3 per cent. less than the Daniell.'

[2] '*Journal of the Chemical Society*, 2nd series, vol. vi. p. 488: *Comptes Rendus*, 1868, p. 794.'

most striking results is 8 inches (20·23 centim.) long, and has a series of six aluminium rings varying in diameter from $\frac{3}{8}$ of an inch to about $1\frac{1}{4}$ of an inch (0·95 to 3·17 centim.), the thickness of the wire being about $\frac{1}{16}$ of an inch (0·16 centim.); the rings are a little more than 1 inch (2·54 centim.) apart; and connecting wires of platinum pass through the tube from each ring, and permit of the length and other conditions of the discharge being varied.

'At times the terminals of the battery were placed in connection with accumulators of different kinds—for instance, two spheres of 18 inches (45·72 centim.) in diameter, presenting each a superficies of 7·07 square feet (65·68 square decim.), and cylinders of paper covered with tinfoil, each having a surface of 16 square feet (148·64 square decim.); the globe and cylinders were in all cases carefully insulated. Other accumulators were composed of coils of two copper wires $\frac{1}{16}$ of an inch (0·16 centim.) in diameter, covered with gutta-percha, in two folds, $\frac{1}{32}$ of an inch (0·08 centim.) thick. One coil contains two wires, coiled side by side, each being 174 yards (159 metres) long, another with two wires, each 350 yards (320 metres); of the latter we have two coils.

'In addition to these accumulators we have several others formed of alternate plates of tinfoil and insulating material, such as paper saturated with paraffine, and also sheets of vulcanite. These are of various capacities, and contain from five to several hundred square feet. The largest has a capacity of 47·5 microfarads; when it is discharged it gives a very bright short spark, accompanied by a loud snap; the charge deflagrates 8 inches (20·32 centim.) of platinum wire, 0·005 inch (0·127 millim.) in diameter, when it is caused to pass through it. Each accumulator gives different results; but for the present we shall confine ourselves to a description of the experiments made with the coil-accumulators.

'When the terminals of the battery are connected with the wires of a vacuum-tube which permits of the passage of the current, the wires (especially that connected with the zinc end) become surrounded with a soft nebulous light, in which several concentric layers of different degrees of brilliancy are seen; in most cases there is either no indication of stratification, or only a feeble, ill-defined tendency to stratification: the tubes selected for these experiments were those in which the stratification did not appear at all.

'When the battery, already in connection with the vacuum-tube, was also joined on to one or more coil-condensers (coupled to introduce a greater length of wire), then immediately well-defined stratifications appeared in the vacuum-tube.

'It may be stated that the capacity of the accumulator has to be carefully adjusted to prevent any cessation of the current, to avoid, in fact, a snapping discharge at distant intervals. The periodic overflows, so to speak, which increase the current from time to time, would seem to have a tendency to cause an interference of the current-waves, and to produce nodes of greater resistance in the medium, as evinced by the stratification which becomes apparent. To the eye no pulsation in the current is apparent; and in order to convince ourselves whether or not there was really any fluctuation in the current when the apparatus was thus coupled up with the battery, we made several experiments, and ultimately hit upon the following arrangement.

'The primary wire of a small induction-coil, both with and without the iron core, was introduced into the circuit as well as the vacuum tube; to the secondary wire of the induction-coil was connected a second vacuum-tube. Under these circumstances there was no change in the appearance of the discharge in the vacuum-tube, in consequence of the introduction of the induction-coil, the terminals being still surrounded by the soft nebulous light before spoken of: no luminosity appeared in the second vacuum-tube in connection with the secondary wire of the induction-coil, except on making and breaking the connection with the battery. At other times there was evidently no fluctuation in the continuous discharge, no periodic increase or diminution of flow, and consequently no induced current in the secondary wire of the induction-coil.

'In the second experiment wires were also led from the terminals of the battery (all other things remaining as before) to the coil-accumulator, then immediately the discharge in the first vacuum-tube became stratified and the secondary vacuum-tube lighted up clearly, showing that under these circumstances a fluctuation in the discharge really occurs on the appearance of stratification.

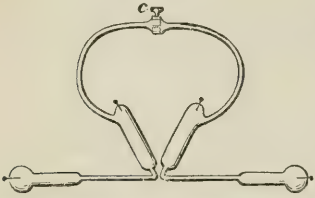
'The brilliancy of the discharge in the second vacuum-tube (the induced current passes through complicated vacuum-tubes through which the primary current cannot pass) depends greatly on the quality and quantity of the discharge in the primary vacuum-tube. Under some circumstances the secondary discharge is extremely feeble, and the illumination barely visible; under others it is very brilliant.'[1]

(213) **Electrical Spectra of Highly Attenuated Gases.**—In order to observe and analyse the spectra produced by different

[1] Mr. de la Rue has since increased his battery to 11,000 cells, and has obtained proportionately increased brilliant effects.

gases, Plücker concentrated the luminous electrical discharge current in thermometer tubes whose internal diameters were nearly the same for the different gases examined, viz. about 0·6 millimetre. The form of the tube is shown in Fig. 300. By turning the glass cock *c* the gases in the two tubes could be put into communication. The spectra were observed by means of a telescope (such as that employed by Fraunhofer in his observation of the lines of the solar spectrum), without angular measurements. This was set up at a distance of from 4 to 5 metres from the vertical line of the tube. The flint glass prism, whose refractive angle was 45 degrees, was fastened immediately before the object-glass, whose aperture was 15 Parisian lines. The following results were obtained by Plücker :—

Fig. 300.



1. *Hydrogen.*—Almost the whole of the light is concentrated into three bands: viz. a dazzling *red* at the extremity of the spectrum ; a beautiful greenish *blue* ; and a *violet* of inferior brightness, whose distance from the greenish blue is about two-thirds of the distance of the latter from the red. In the narrow tube the electric light stream appears *red.*

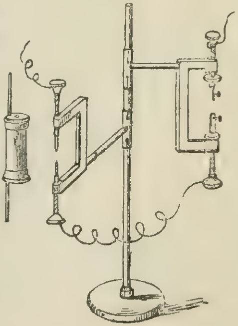
2. *Nitrogen.*—In the spectrum of this gas all the colours are fine, none of them being faded as in the broad space lying between the bright bands of the hydrogen spectrum. In the spaces of the red, orange, and yellow, there are about fifteen narrow dark grey lines at nearly equal distances apart. Six of these belong to the orange and yellow ; both of these colours are beautiful. The red in the direction away from the orange is shaded off into brown, but becomes brighter and purer towards the extremity of the spectrum which stretches beyond the dazzling red bands of the hydrogen spectrum. A broad green space is separated from the yellow by a narrow black band. The greater part of this space appears shaded with black in the direction away from the black band. On a more careful examination, this shading is seen to consist of very fine black lines, which are at equal distances apart, but nearer together than the previously-mentioned bands on the red, orange, and yellow. The rest of the green space is again subdivided. The green is bordered by two beautiful bright blue bands, which are sharply separated from one another, and from the green by narrow black bands. The blue and red violet ends of the spectrum form *nine* sharply bordered violet bands, alternating with dark ones. The fourth and fifth bright bands, separated by a black band, possess the most light ; the four following ones are less prominent. The last one, however, which forms a sharp boundary to the whole spectrum, is most distinct. The light of the discharged current in the narrow tube is *yellowish red.*

3. *Carbonic Acid.*—Six bright bands sharply separate the bright portion into five spaces, of which the two first are of equal breadth ; the third, and especially the two last, are somewhat broader. The first of the six bands

is situated on the extreme boundary of the red; the second is *reddish orange*; the third *greenish yellow*; the fourth *green*; the fifth *blue*; and the last *violet*. Both of the two first spaces are divided into three equally broad subdivisions, by narrow black grey bands, of which two always border upon the bright band. The first space is *brown red*; the second *dirty orange* and *yellow*; the third and fourth spaces are rather *faded green*; the fifth space, which is very faded, is divided into two equal spaces, which are shaded off from the red side towards the violet. After the last-mentioned violet band, another dark portion of the spectrum occurs, about as wide as the red-yellow portion. In this dark portion three spaces are separated by three prominent and well-marked violet bands, whose breadth is of the same value as that of the before-mentioned six bands. The first of these three spaces, which is contiguous to the above six bright bands, is somewhat broader than the third. Both are perfectly black. The second and middle space is about as broad as the first and third together, and is of a very dark violet colour. The first band, which at the moment of commencing was of an especially brilliant red, lost almost the whole of its brightness after the streams had passed through the tube for a long time. This was occasioned by the decomposition of the gas into *carbonic oxide* and *oxygen*, the latter combining with the platinum of the negative electrode, and forming oxide of platinum, which was deposited of a yellow colour upon the neighbouring internal surface of the glass.

With *oxygen* Plücker could not obtain a good spectrum on account of its gradual disappearance and combination with the platinum of the electrode; *binoxide of nitrogen* was decomposed, giving, after some little time, the pure spectrum of nitrogen gas in great splendour; *aqueous vapour* was likewise decomposed, and the spectrum of hydrogen produced; with *ammonia* the spectra of hydrogen and nitrogen superposed were obtained.

Fig. 301.

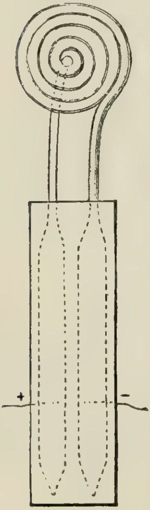


For experimenting upon the spectra produced by different metals, comparing them with that produced by platinum, the arrangement shown in Fig. 301 is found very convenient. The metals, in the form of wires, are attached to screws, passing through clamps of vulcanite, which can be adjusted at any required height and angle by means of the spring tubes connecting them with the upright pillar. The wires on the left-hand clamp are permanently platinum; those on the right-hand clamp may be of any other metal or metals; they are held by pincers, so that they may readily be removed and replaced by others; the two lower screws are connected metalli-

cally. The two upper are connected with the secondary terminals of the coil, and then with the Leyden jar. A brilliant discharge takes place simultaneously between the wires in each clamp, provided the distances be properly adjusted, and the apparatus being accurately arranged before the spectrum-box; one spark is reflected through a prism, and the other is received directly through the slit; the two spectra immediately become apparent one over the other, so that the peculiarities in each case may be at once detected. By employing the little capped glass tubes shown on the left-hand side of the figure, spectra may be obtained in various gases, the gases being passed through the tube while the discharge is taking place.

(214) **Application of Electrical Discharges from the Induction Coil to the Purposes of Illumination.**—The simple apparatus shown in Fig. 302 was devised by Mr. Gassiot for this purpose. It represents a carbonic acid vacuum-tube of about one-sixteenth of an inch internal diameter, wound in the form of a flattened spiral. The wider ends of the tube, in which the platinum wires are sealed, are about two inches in length, and half an inch in diameter, and are shown by the dotted lines. They are enclosed in a wooden case (indicated by the surrounding entire line), so as to permit only the spiral to be exposed. When discharge from the induction coil is passed through the vacuum-tube, the spiral becomes intensely luminous, exhibiting a brilliant white light. With a coil so as to give a spark through air of about one inch in length, the luminosity of the spiral is not reduced when the discharge passes through 14 miles of copper wire.

Fig. 302.



A mode of applying the electric light for mining purposes has been adopted by MM. Dumas and Benoit (*Comptes Rendus*, Sept. 8, 1862). The apparatus consists essentially of three parts:—1. a battery; 2. a Ruhmkorff coil; 3. a Geissler vacuum-tube; the whole being arranged in such a manner as to produce a sufficient light to illuminate the miner, and allow him to work when other lights fail. The greatest difficulty in the arrangement consists in being able to construct a battery which shall possess sufficient intensity to keep up a regular light for at least twelve hours in a convenient and portable form; this the

authors state that they have accomplished, the whole apparatus being so small that the miner can carry it without inconvenience in a small carpet-bag.

The advantages of this mode of illumination are that the light produced is cold, or rather does not heat the tube in which it is produced, and that the gas of the mine has no access to it, it being completely isolated. It is, moreover, quite as compact as ordinary lamps, and there is no injurious emanation, and it can be lighted and extinguished at will.

(215) **Condensers and Leyden Jars Charged by the Induction Coil.**—In 1835, Masson (*Prize Essay*, *Haerlem*) made a series of experiments by which he proved that a condenser may be charged by the induction coil machine. He placed the two poles of the coil in connection with the coatings of the condenser, which coatings he at the same time connected with an insulated Lane's discharger, the balls being one-fiftieth of an inch apart; he thus obtained a permanent discharge, surpassing in intensity that of the direct discharge of the apparatus, in a degree proportional to the size of the condenser and the number of the elements of the battery.

Grove and Gassiot (*Phil. Mag.*, Jan. 1855) repeated these experiments on a much larger scale, and with results of a singularly interesting character. When a Leyden phial was interposed between the terminals of the secondary coil, the *exterior* pole being connected with the interior of the jar, the noise and brilliancy of the discharges were greatly increased, but no advantage was gained by increasing the number of the cells of the battery; on the contrary, the platinum contact-breaker was thereby rapidly burnt. When, however, a phial of double the capacity was employed, the brilliancy of the discharge spark was again increased, and on adding more coated surface, a fresh addition could be made to the battery, with a further increase in the effects, and without any injurious action taking place at the contact-breaker.

The difference between the ordinary induction spark and that produced when the secondary terminals are connected respectively with the inner and outer coating of a Leyden jar is very striking: in the former it is flamelike, soft, and quiet; in the latter it is bright, sonorous, and apparently large; but while the rattling spark cannot easily fire wood, paper, or even gunpowder, the soft spark at once inflames either of them. The effect of the static induction thus introduced is not so much to vary the *quantity* of electricity which passes as the *time* of the passage. That electricity which, moving with comparative slowness through the great length of the secondary coil, produces a spark having a sensible duration (and

therefore in character like that of a Leyden jar passed through a wet thread) is, when the jar is used, first employed in raising up a *static induction* charge, which, when discharged, produces a concentrated spark of no sensible duration, and, therefore, much more luminous and audible than the former.

This difference in the character of the two sparks is well illustrated in the following experiment (Faraday, *Notices of the Meetings of the Royal Institution*, June 8, 1855):—

A piece of platinum wire is fixed horizontally across the ball of a Leyden jar, and the platinum wire secondary terminals brought respectively near its ends; two interruptions are thus produced in the secondary circuit, the sparks at which are like each other, and equal in quantity of electricity, the jar as yet forming only an insulating support. But if in addition, either secondary terminal be connected by a wire with the outside of the jar, the spark on that side assumes the bright loud character before described, but ceases to fire gunpowder or wood; and nobody would at first suppose (what is really the case) that there is the same electricity passing in one as in the other.

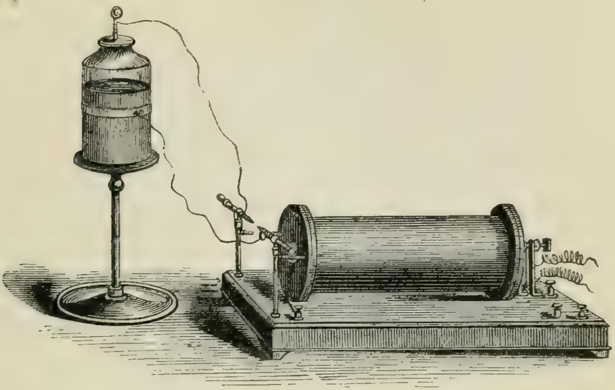
If one of the secondary terminals be connected with the outside of the Leyden jar, and the other be brought near the knob, a soft spark appears at that interval for every successive current in the primary circuit. This spark is, however, *double*, for the electricity thrown into the jar at the moment of induction is discharged back again at the same place the instant the induction is over. The first discharge heats and prepares the air there for the second discharge, and the two are so nearly simultaneous as to produce the appearance of a single spark to the unaided eye.

In all these experiments the *exterior* pole of the secondary wire must be in contact with the knob of the jar, unless it be insulated, in which case it is immaterial which way the connections are made. When two coils are properly connected together through their primaries and secondaries, and a battery of from 10 to 15 cells of the nitric acid battery employed, the extent of coated surface may be increased to 7 square feet; the discharge sparks are then fully $\frac{3}{4}$ of an inch in length, piercing stout card, and accompanied by a loud and continuous noise.

With Ruhmkorff's large coil (202), electrical batteries may be charged and discharged with a continuous and almost deafening noise. The most brilliant effects are, however, produced by charging a series of jars by *cascade* (Fig. 46, p. 48). When six jars, each containing about two square feet of coated glass, are employed, a continuous stream of the most dazzling light, 6 inches in length, is produced, accompanied by a noise that cannot long be endured. With one jar, the discharge spark is $2\frac{1}{2}$ inches long; with two jars, $3\frac{1}{2}$ inches; with three jars, $4\frac{1}{4}$ inches; with four jars, 5 inches and with five jars, $5\frac{1}{2}$ inches.

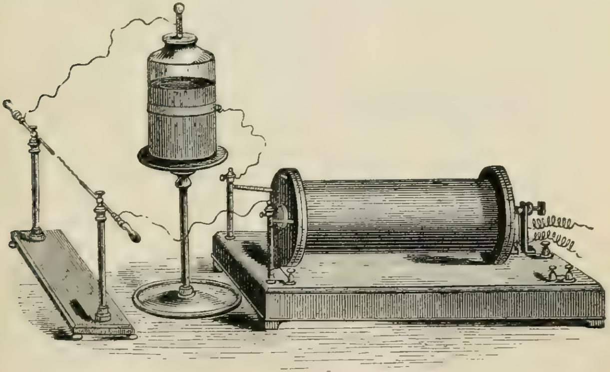
The manner of arranging a Leyden jar for continuous charging and discharging by the alternating induced current is shown in Fig. 303, the outer and inner coatings being respectively in communication with the poles of the secondary coil, and the terminals

Fig. 303.



of the discharger being set about one inch apart; the jar becomes constantly charged by the coil, and discharged between the points of the discharger.

Fig. 304.



But the jar may be charged by the coil in such a manner as to retain its charge, as when it is charged in the usual manner by the

conductor of an electrical machine. For this purpose, it is arranged as shown in Fig. 304; the outer coating is brought into communication with one of the poles of the coil, and the inner with one of the arms of the discharger, the other arm of which is in communication with the other pole of the coil; the points of the discharger are set two or three inches apart.

Now it must be remembered that, when the poles of the secondary coil are connected by a metallic wire, or other good conductor, there are two currents moving through it alternately in opposite directions, but that, when the poles are separated, *one* only of these waves or currents is brought into action, that, namely, produced when battery contact with the primary is broken, which is by far the most intense; the other wave, that produced by making battery contact, is stopped off from the secondary wire, being expended in the primary wire itself, as has already been stated (198). The jar, therefore, receives not an alternating but a direct charge, and after a few sparks have passed, it may be removed and discharged in the usual manner. With Ruhmkorff's large instrument above described (202), a battery containing 10 square feet of glass is charged to saturation in a few seconds.

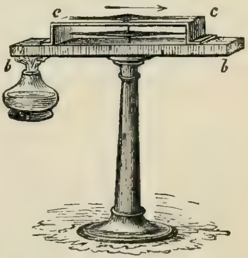
CHAPTER XVI.

THERMO-ELECTRICITY.

Discovery—Thermo-electric Series—Thermo-electric Piles and Batteries—Nobili—Bunsen—Becquerel—Clamond—Wray—Laws of Thermo-electricity—Absorption and Generation of Heat—Thermo-currents from Fused Salts.

(216) **Seebeck's Discovery.**—In the year 1821, Professor Seebeck, of Berlin, ascertained that electrical currents may be excited in all metallic bodies by disturbing the equilibrium of temperature, the essential conditions being that the extremities should be in opposite states as regards temperature. His apparatus was remarkably simple: it consisted of two different metals (antimony and bismuth were found the most efficient) soldered together at their extremities, and formed into frames of either a circular or a rectangular figure. Electricity was excited by heating one of the compound corners by the flame of a spirit lamp, and cooling the opposite corner by wrapping a few folds of filtering paper round it, and moistening it with ether.

Fig. 305.

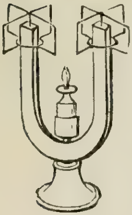


In Fig. 305, *c c* is a plate of copper, the ends of which are bent at right angles, and soldered to a plate of bismuth, *b b*; a magnetised needle is balanced in the interior of the circuit. The apparatus being placed in the magnetic meridian, one of the junctions of the metals is heated by a spirit-lamp, the needle is immediately deflected, showing the passage of an electrical current in the direction of the arrow-head, *i.e.* from the hot to the cold end.

In Fig. 306, two frames composed of platinum and silver wires are delicately poised on the poles of a horseshoe magnet, a spirit-lamp being placed between them, the flame of which causes the circulation of thermo-electric

currents in the wires, as shown by their rotation round the poles of the magnet.

Fig. 306.



If the extremities of two platinum wires be each coiled into a flat spiral and the other ends connected with a delicate galvanometer, a current of electricity will be determined through the instrument by merely heating one spiral to redness and laying it on the other, the flow of the current being from the hotter to the colder portion.

If portions of a metallic wire be stretched by weights, and connected with other portions of the same wire not so stretched, it was in 1856 shown by Sir William Thomson, that on applying heat to their junctions, a current is determined from the stretched to the unstretched wire through the heated point.

(217) **Thermo-electric Series.**—Experiments have shown that the thermo-electric properties of metals have no connection with their voltaic relations, or with their power of conducting heat or electricity; neither do they accord with their specific gravities or atomic weights. In forming a thermo-electric series, it is desirable to combine an extreme positive with an extreme negative metal. The following series was arranged by Professor Cumming. When any of these metals are heated at their point of junction, electrical currents are developed in such a manner that each metal becomes positive to all below and negative to all above it in the list, and the reverse order is observed if the point of junction be cooled:—

Galena	Rhodium
Bismuth	Gold
Mercury }	Copper
Nickel }	Silver
Platinum	Zinc
Palladium	Cadmium
Cobalt }	Charcoal
Manganese }	Plumbago
Tin	Iron
Lead	Arsenic
Brass	Antimony

The following thermo-electric order and energy of various bodies for temperatures usually ranging between about 40° and 100° has been published by Matthiessen (*Phil. Trans.*, 1858). In the table the electromotive force of the thermo-current excited between silver and copper is taken as equal to 1, the current passing from the silver to the copper at the heated end. The numbers represent the force of the current between silver and each metal in succession, heated to the same point. Where the positive sign is pre-

fixed, the current is from the silver to the other metal at the heated junction; where the negative sign is prefixed, the current is from the other metal at the heated point towards the silver. The asterisks denote that the metal by which it is placed was supposed to be chemically pure:—

Thermo-electric Order of Metals, &c., according to Matthiessen.

	+		−
Bismuth, commercial pressed wire	35·81	Gas coke, hard	0·057
*Bismuth, pressed wire	32·91	*Zinc, pressed wire	0·208
*Bismuth, cast	24·96	*Copper, voltaic	0·244
Crystallised Bismuth, axial	24·59	*Cadmium	0·332
Crystal of Bismuth, equatorial	17·17	Antimony, pressed wire	1·897
Cobalt	8·97	Strontium	2·028
Potassium	5·49	Lithium	3·768
Nickel	5·02	*Arsenic	3·828
Palladium	3·56	Calcium	5·260
Sodium	3·094	Iron, piano wire	5·218
*Mercury	2·524	Antimony, axial	6·965
Aluminium	1·283	Antimony, equatorial	9·435
Magnesium	1·175	*Red phosphorus	9·600
*Lead, pressed wire	1·029	*Antimony, cast	9·871
*Tin, pressed wire	1·000	Alloy, 12 bismuth, 1 tin, cast	13·670
Copper wire	1·000	Alloy, 2 antimony, 1 zinc, cast	22·70
Platinum	0·723	*Tellurium	179·80
Iridium	0·163	*Selenium	290·0
*Antimony, pressed wire	0·036		
*Silver	0·000		

The following table, prepared by Professor Tait, gives the temperature at which certain metals are neutral to each other:—

Iron	+ 357
Tin	+ 45
Brass	+ 27
Lead	—
Zinc	− 32
Copper	− 68
Cadmium	− 69
Aluminium	− 113
Silver	− 115
Palladium	− 181
German silver	− 314

(218) **Thermo-electric Piles and Batteries.**—The arrangement of the thermo-pile invented in 1834 by Nobili and Melloni is shown in Figs. 307 and 308. It is composed of a series of small bars of antimony and bismuth, placed parallel side by side, forming one prismatic bundle about $1\frac{1}{4}$ inch long, and somewhat less in

diameter. The bars of bismuth which succeed alternately to those of antimony are soldered at their extremities to the latter metal,

Fig. 307.

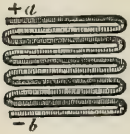
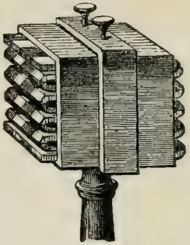


Fig. 308.



and separated at every other part of their surfaces by some insulating substance, such as silk and paper. The first and last bars have each a copper wire which terminates in a peg of the same metal passing through a piece of ivory fixed in a ring; the space between this ring and the elements of the pile is filled with some insulating substance. This apparatus was employed by Melloni in his experiments on radiant heat. The loose extremities of the copper wires are connected with the ends of the wire of a galvanometer which indicates by the motion of the needle any variation in the temperature of the opposite faces of the pile.

Two forms of the thermo-electric batteries are shown in Figs. 309 and 310.

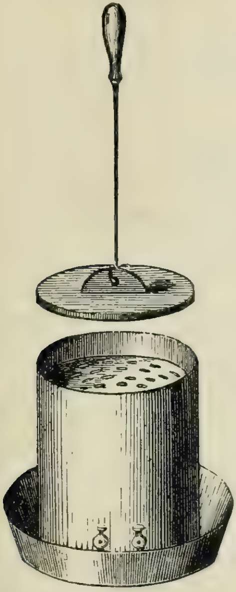
Locke's thermo-battery (Fig. 309) is composed of from 30 to 100 series of bars of antimony and bismuth, soldered together at their extremities and placed in a metallic cylinder, which is then filled with plaster of Paris, leaving merely the extremities of the bars exposed. The first bar of bismuth is connected with one of the binding screws, and the last antimony bar with the other. The instrument is put in action by placing it on a vessel of ice, and then laying a hot iron plate on the top.

Watson's massive thermo-battery is shown in Fig. 310. It consists of an association of square bismuth and antimony plates alternately soldered together so as to form a composite battery, mounted in a frame, with the upper and lower junctions of metal exposed. When either of the ends are slightly elevated or depressed in regard to temperature, the electric current is established, and with the radiation of red-hot iron at one extremity, and ice at the other, all the ordinary electric phenomena, such as the spark, heat, electro-magnetic rotations, chemical action, &c., are developed.

Professor Dove employed iron and platinum soldered together in alternate lengths, and the whole wound on a cylinder of such diameter, as to bring all the iron-platinum junctions on one side of the cylinder, and all the platinum-iron junctions on the other.

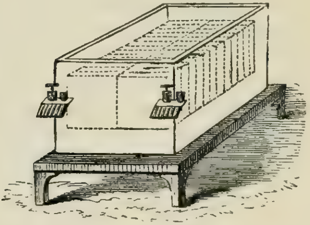
Farmer, in America, used Markus metal and German silver, but failed to secure a good permanent connection.

Fig. 309.



Instead of bismuth and antimony, Bunsen used as the elements of his thermo-battery copper pyrites combined with copper, or *pyrolusite* combined with copper or platinum. Ten of such combinations give all the actions of a Daniell battery, having an effective copper surface of 14 square centimetres (2·17 square inches) in area. Stefan employed granulated sulphide of lead for the positive, and copper pyrites for the negative element—the power of a single pair, as compared with a

Fig. 310.



Daniell's cell, is stated to be as 1 to 5·5. Marcus, in Germany, used for the positive metal an alloy composed of

Copper . . .	10 parts
Zinc	6 parts
Nickel	6 parts

and for the negative an alloy composed of

Antimony	12 parts
Zinc	5 parts
Bismuth	1 part

The elements of his battery are about 7 inches long, 7 lines broad, and half a line thick; they are screwed together, and so arranged that their lower junctions can be heated by a row of gas jets, and the upper cooled by a current of water. The electromotive force of one element is equal to one-twenty-fifth of a Bun-

sen's cell. *Six* pairs decompose water; *thirty* pairs cause an electro-magnet to lift 150 lbs.; and *one hundred aad twenty-six* pairs decompose water at the rate of 25 cubic inches of mixed gases per minute, and melt a platinum wire half a millimetre in thickness.

The conversion of heat into electricity by this battery, is strikingly shown by the fact that the water used for cooling the upper junctions, is more rapidly warmed when the current is broken, than when it is closed.

It was stated by Marcus, in a communication to the Austrian Academy of Sciences, that he had constructed a furnace consuming 240 lbs. of coal per day, intended to heat 768 elements of his thermo-battery, the electromotive power of which would be equivalent to 30 cells of Bunsen's nitric acid arrangement.

Wheatstone constructed a thermo-pile on Marcus's principle, the electromotive force of which was equal to *two* Daniell's cells; he found that its power was greatly increased by repeatedly melting the alloy composing the bars, probably in consequence of their crystalline structure being thereby broken down. *Sixty* of Wheatstone's elements produce the following effects:—They give a brilliant spark; raise to incandescence and fuse half an inch of fine platinum wire; decompose water; electroplate copper with silver; make an electro-magnet lift $1\frac{1}{2}$ cwt.; and give bright sparks from the primary and secondary coils of a Ruhmkorff induction coil: in fact, they reproduce all the effects obtainable from a voltaic battery.

Sir William Thomson discovered the singular fact, that when a metal circuit is heated at one spot, and a current is passed through it, the heat is conveyed by the current in a direction dependent on the nature of the metal. With iron or platinum, the heat is carried by the positive current from hot to cold, with copper and other metals in the reverse direction.

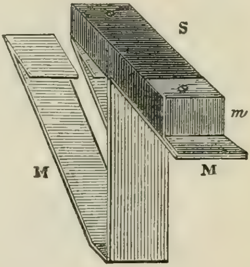
(219) **Thermo-electric Pile of Ed. Becquerel.**—M. Becquerel, sen., had observed, as far back as 1827, that a copper wire, coupled with a wire of similar metal, sulphuretted on the surface, gave, by an elevation of the temperature of one of the contacts from 200° to 300°, a thermo-electric couple much more energetic than those which can be obtained with other metals.

M. Ed. Becquerel (see *Ganot, Traité de Physique,* 15th edit.), having carried on some researches in 1865, upon the thermo-electric power of artificial sulphuret of copper, found that this substance, heated to 200° or 300°, was strongly positive, and that a couple of this sulphuret of copper and of copper has an electromotive force nearly ten times greater than that of a bismuth-copper

couple. Native sulphuret of copper is, on the contrary, strongly negative.

As the artificial sulphuret only melts at about 1035°, it may be used at very high temperatures. The metal joined with it is German silver (90 of copper and 10 of nickel). The arrangement of a battery is as follows:—The sulphuret is cut in the form of rectangular prisms, 10 centimetres in length, 18 mm. in breadth, and 12 mm. thick. In front (Fig. 311) is a plate of German silver *m*, intended to protect the sulphuret from roasting when it is placed in a gas flame. Below there is a plate of German silver M M, which is bent several times, so as to be joined to the sulphuret of the next, and so on. The couples, thus arranged in two series of 25, are fixed to a wooden frame supported by two brass columns, on which it can be more or less raised. Below the couples there is a brass trough, through which water is constantly flowing. The plates of German silver are thus kept at a constant temperature. On each side of the trough are two long burners on the Argand principle, fed by gas from a caoutchouc tube. The frame being sufficiently lowered, the ends are kept at a temperature of 200° to 300°. For collecting the current, two binding screws are placed on the left of the frame, one communicating with the first sulphuret—that is, the positive pole—and the other with the last German-silver or negative pole. At the other end of the frame are two binding screws, which facilitate the arrangements of the couples in various ways.

Fig. 311.



The resistance of sulphuret of copper is great, and consequently the current can acquire great tension. It may be used for telegraphing at a distance, and, charging an electro-magnet, can lift a weight of 200 pounds. It can heat a short piece of fine iron wire to redness, and freely decomposes water. The electromotive force of a Daniell's cell is equal to about 8 or 9 of these couples.

(220) **Clamond's Thermo-electric Battery.**—One of the greatest improvements introduced in thermo-electricity has been that of the 'Clamond Pile.' M. Clamond has been for many years working on the subject of thermo-electricity, with a view of bringing it into real practical use, and he patented in 1868 his first thermo-pile, in which was employed a sulphuret of lead in the form of native galena and iron. That mode of construction was

abandoned in favour of his present well-known system, which has been brought to great perfection, and which was patented in 1874.

In a paper read before the Society of Telegraph Engineers by Mr. Latimer Clark, on April 26, 1876 (vol. v. p. 321), the present thermo-pile is thoroughly described.

'The mixture employed by Clamond consists of an alloy of two parts of antimony and one of zinc for the negative metal, and for the positive element he employs ordinary tinned sheet-iron, the current flowing through the hot junction from the iron to the alloy. The combination is one of great power. Each element consists of a flat bar of the alloy, from 2 inches to $2\frac{3}{4}$ inches in length and from $\frac{3}{8}$ths to 1 inch in thickness. Their form is shown in Fig. 312, by which it will be seen that, looked at in plan, they are spindle-shaped, or broader in the middle than at the ends. The

Fig. 312.

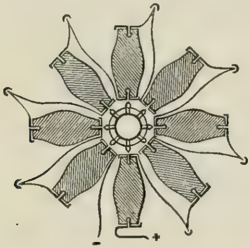
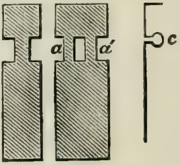


Fig. 313.



sheet tin is stamped out in the form shown in Fig. 313; the narrow portion is then bent into the forms shown, in which state they are ready for being fixed in a mould.

'The melted alloy is poured in, and before it has cooled the mould is opened and the bars removed with the lugs securely cast into them. The mould is heated nearly to the melting point of the alloy, and 10 or 12 bars are cast at one time. A little zinc is added from time to time to make up for the loss due to volatilisation. The alloy melts at a temperature of about 500° Fahrenheit; it expands considerably in cooling. The more frequently the alloy is recast the more perfect becomes the mixture, so that old piles can be reconverted with advantage and with little loss beyond that of the labour. The alloy is extremely weak and brittle and easily broken by a gentle blow—in fact, it is scarcely stronger than loaf sugar.'

'The tin lugs are bent into form, and the bars are arranged in a radial manner round a temporary brass cylinder, as shown in Fig. 312, a thin slip of mica being inserted between the tin lug and

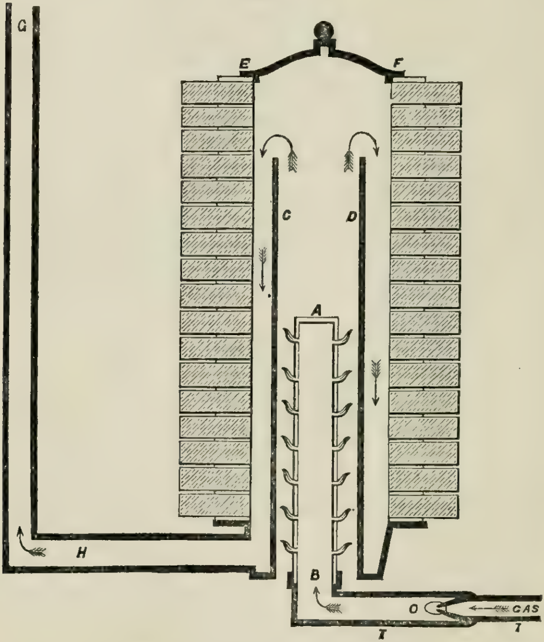
the alloy to prevent contact except at the junction. The number of radial bars varies with the size of the pile, but for the usual sizes eight or ten are employed. As fast as the bars are laid in position they are secured by a paste or cement formed of powdered asbestos and soluble glass or solution of silicate of potass; flat rings are also formed of the same composition, which possesses considerable tenacity when dry, and as soon as one circle of bars is completed a ring of the dry asbestos cement is placed upon it, and another circle of elements is built upon this, and so on until the whole battery is formed. Cast-iron frames are then placed at top and bottom of the pile and drawn together by screws and rods, so as to consolidate the whole, and in this condition the pile is allowed to dry and harden. Looked at from the inside, the faces of the elements form a perfect cylinder, within which the gas is burned. The inner face of each element is protected from excessive heat by a tin strip or cap of tin bent round it before it is embedded in the cement; the projecting strips of tin from the opposite ends of each pair of elements are brought together and soldered with a blowpipe and soft solder. The respective rings are similarly connected, and the whole pile is complete except as regards the heating arrangements. The positive pole of these piles is always placed at the top. Cumming was the first to use this stellar arrangement of couples.

'The pile is usually heated by gas mixed with air, on the Bunsen principle; the gas is introduced at the bottom of a tube of earthenware, which is closed at the top, and is pierced with a number of small holes throughout its length, corresponding approximately in number and position with the number of elements employed. Before entering this tube the gas is allowed to mix with a regulated proportion of air by an orifice in the supply tube, the size of which can be adjusted; the mixed gases escape through the holes in the earthenware tube and there burn in small blue jets, the annular space between the gas tube and the elements forming a chimney, to which air is admitted at bottom, the products of combustion escaping at the top.

'In order to prevent injury from over-heating, and to diminish the consumption of gas, M. Clamond has introduced a new form of combustion chamber, by which he obtains very great advantages. This form is shown in Fig. 314. The mixture of air and gas is burnt in a perforated earthenware tube, as before described, but instead of extending the whole height of the battery, it only extends to about one-half of its height. The earthenware tube is surrounded by an iron tube of larger diameter, which extends nearly to the top of the battery, and is open at the top. Outside

this iron tube, and at some distance from it, are arranged the elements in the usual manner. A movable cover fits closely over the top of the pile, and a chimney is connected to the bottom of the pile, leading off from the annular space between the iron tube and the interior faces of the elements. The air enters at the bottom of the iron tube, and the heated gases passing up the tube curl over at the top and descend on its outside, escaping eventually by the chimney. The elements are heated partly by radiation from the

Fig. 314.



iron tube, and partly by the hot gases which pass outside the tube downwards towards the chimney. By this arrangement not only is great economy of gas effected, the consumption, as I am informed, being reduced by one-half, but the great advantage is obtained that the jets of gas can never impinge directly on the elements, and it is thus scarcely possible to injure the connections by overheating. In the event of a bad connection occurring, it is easy to find out the imperfect element and throw it out of use by short-

circuiting it over with a piece of wire, and the makers have no difficulty in cutting out a defective element and replacing it by a sound one.

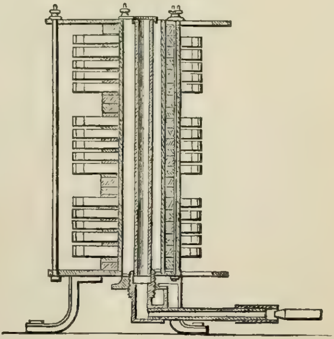
'Coke and charcoal have also been employed as a source of heat, with very great economy and success; in fact, there are many countries and places where gas would not be procurable, but where charcoal or coke could be readily obtained.

'The tension produced by Clamond's thermo-elements is such that each 20 elements may be taken as practically equal to one Daniell's cell or one volt.

'A large number of these piles have been in use in this country, and a still greater number in France. Some extensive practical experiments were made as to the use of the pile for working telegraph circuits. The Post Office authorities employed at the General Post Office five pairs of Clamond's thermo-piles in working circuits on what is called the universal battery system—that is, working many circuits from the same set. Three were employed first in working 22 circuits, which were gradually increased to 42; and the two others were employed in working first 20, which were gradually increased to 48: so that these 5 thermo-piles were used in working 90 separate and distinct circuits from the General Post Office. These circuits were all under 100 miles in length. The piles, however, gradually failed from the over-heating, by which the connection between the two plates was fused or destroyed. The improved form has not been tried in this direction.'

(221) **Wray's Thermo-electric Pile.**—In 1876 Messrs. L. and C. Wray patented an improved form of thermo-electric pile, which may be seen in Fig. 315. Their first improvement (*Journal of the Society of Telegraph Engineers*, vol. v. p. 351) is in the manner of casting the bars. They are cast under pressure, as they always have been, and the change consists in the use of a small tongue of tinned iron cast down the centre of the bar (Figs. 316, 317), extending nearly its whole length. This adds materially to the strength, and it is stated that it also decreases the resistance and increases the electromotive force. At

Fig. 315.



any rate, it increases the strength in the proportion of about 30 to 50, so that the couples are not so fragile as before.

Fig. 316.

Fig. 317.

The next improvement is in the method of building up the battery. The battery is built up by a number of discs made up of burnt clay, pipe-clay, or biscuit ware, and between each disc interposes a small triangle of the same material, with metal rods to hold the whole together. The consequence is, these discs and triangles, when in place, sustain the whole pressure, and the thermo-bars rest upon them, and can be removed and re-arranged when necessary; by this improvement they are not so liable to be injured by the heat of the gas.

The third improvement is in the method of heating. Instead of the gas flames impinging directly upon the bars or against the iron cylinder within the thermo-battery, they now employ an inner cylinder of earthenware, which forms the centre of the battery, and they build up the bars of metal around the cylinder, and in close contact with it, each bar being bedded up against it with asbestos cement. The flame, therefore, cannot get in contact with them, and they are less liable to be injured by heat, which was the chief cause of difficulty in the older form of pile; another advantage is that the heat is more uniformly distributed. Further improvements have been made in the gas chamber, and also in the regulation of the supply of air and of gas. The supply of air is further regulated by little covers of fire-clay (consisting of perforated radial discs), placed on the top of the battery.

(222) **Laws of Thermo-electricity.**—Ganot, in his *Traité de Physique*, gives the following as the laws of thermo-electric currents as stated by M. Becquerel:—

1. In a thermo-electric couple, so long as the difference in temperature between the two junctions remains the same, the current is rigorously constant.

2. In a thermo-electric pile, the intensity of the current, all else being equal, is proportional to the number of couples.

3. The intensity of thermo-electric currents increases with the difference of temperature between the junctions; and if one be at zero, this intensity is proportional, within the limit of 40° to 45°, to the temperature of the other junction.

In the third law, the limit of 45° is applicable to a copper-antimony couple, but it varies with the metals. For iron and

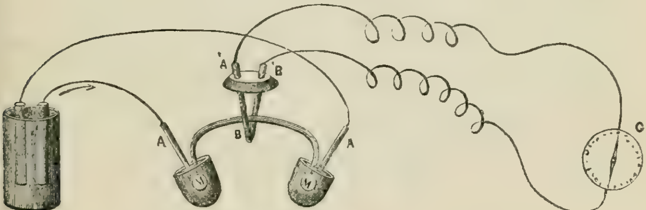
copper it extends as far as 300°, and much above that for iron and palladium.

(223) **Absorption and Generation of Heat.**—Peltier, in 1834, discovered the fact that when electricity traverses a compound metallic conductor from bismuth to antimony, heat is *absorbed*, but that when the current traverses the conductor in the contrary direction, heat is *generated*. The fact is referred to by Joule (*Phil. Mag.*, 1843), as showing how it may be proved that when an electrical current is produced from a purely thermal source, the quantities of heat evolved electrically in the different homogeneous parts of the circuit are only compensations for a loss from the junctions from the different metals; or, that when the effect of the current is entirely thermal, there must be just as much heat emitted from the parts not affected by the source as taken from the source.

Peltier's observation, the accuracy of which had been denied by some experimenters, was confirmed by Tyndal by the following ingenious experiment (*Phil. Mag.*, 1852, p. 419):—

B (Fig. 318) is a curved bar of bismuth, with each end of which a bar of antimony, A A, is brought into close contact; in front of the two junctures

Fig. 318.



are chambers hollowed out in cork and filled with mercury. A current is sent from the cell B″ in the direction indicated by the arrow; at M it passes from antimony to bismuth; at M′ from bismuth to antimony. Now if Peltier's observation be correct, we ought to have the mercury at M warmed, and that at M′ cooled, by the passage of the current. After three minutes' circulation the voltaic circuit was broken, and the thermo test pair A′ B′ dipped into M′; the consequent deflection was 38°, and the sense of the deflection proved that at M′ *heat had been absorbed.* The needles were brought quickly to rest at 0°, and the test pair was dipped into M; the consequent deflection was 60°, and the sense of the deflection proved that at M *heat had been generated.* The system of bars represented in the figure being embedded in wood, the junction at M was cooled slowly, and would have taken a quarter of an hour at least to assume the temperature of the atmosphere.

The voltaic current was reversed, and three minutes' action not only absorbed all the heat at M, but generated cold sufficient to drive the needle through an arc of 20° on the negative side of zero.

It was shown by Lenz (*Pogg. Ann.*, vol. xliv. p. 341) that if two bars of bismuth and antimony be soldered across each other at right angles, and touched with the conducting wires of the battery, so that the current will have to pass from the bismuth to the antimony, a degree of cold sufficient to freeze water may be produced; if a cavity be excavated at the point of contact, and a drop of water, previously cooled to nearly 32°, be placed therein, it will rapidly become ice.

(224) **Thermo-Currents from Fused Salts.**—It has been shown by Dr. Andrews (*Phil. Mag.*, vol. x. p. 433) that an electrical current is always produced when a fused salt capable of conducting electricity is brought into contact with two metals at different temperatures, and that powerful affinities can be overcome by this current, quite independently of chemical action. The direction of the current is not influenced by the nature of the salt or metal, being always from the hotter metal through the fused salt to the colder. Its intensity is greatly superior to that of the common thermo-currents, and is capable of decomposing with facility water and other electrolytes. Dr. Andrews succeeded in decomposing iodide of potassium by the thermo-current produced, by bringing two platinum wires of unequal temperatures into contact with a small globule of fused borax. He found also that currents are produced *before* the salt is actually fused, but that their direction no longer follows a simple law, but varies in a most perplexing manner, being first from the hot metal to the cold, then with the addition of heat from the cold to the hot, and again with a second addition of heat from the hot to the cold.

CHAPTER XVII.

ELECTRIC TELEGRAPHY.

LAND AND AERIAL TELEGRAPHS.

Early Notions—Telegraphs of Ronalds, Sömmering, Schilling, Gauss and Weber, Steinheil, Cooke and Wheatstone—Needle Telegraphs—Alarums—Batteries—Wires—Morse Printing Telegraph—Relays—Type-printing Telegraphs—Magnetic Telegraphs—Acoustic Telegraphs—Dial Telegraphs—Automatic Telegraphy.

(225) **Early Notions of Electric Telegraphy.**—Almost as soon as it had become known that conducting wires had the power of transmitting electricity instantaneously through distances of several miles, it occurred to several electricians that correspondence between distant places might be accomplished by electric action.

There was a fabulous story among the old authors that two needles touched by the same magnet, and suspended within an alphabetic circle, would move in unison at whatever distance they might be separated. The most interesting form of this story is that related by Joseph Glanvill, M.A., in his *Scepsis Scientifica*, published in 1665. He says—

That men should confer at very distant removes by an extemporary intercourse is another reputed impossibility; but yet there are some hints in natural operations that give us probability that it is feasible and may be compassed without unwarrantable correspondence with the people of the air. That a couple of needles equally touched by the same magnet being set in two dyals exactly proportioned to each other, and circumscribed by the letters of the alphabet, may affect this magnate hath considerable authorities to vouch for it. . . . Now, though this pretty contrivance may not yet answer the expectation of inquisitive experiment, yet it is no despicable item that by some other such way of magnetic efficiency it may

hereafter with success be attempted when magical history shall be enlarged by riper inspections, and it is not unlikely but that present discoveries might be improved to the performance.'

From the time that Dr. Watson (35) showed that the electric shock could be transmitted instantaneously through a circuit of two miles and more of water in 1747, there have been numerous contrivances for applying frictional electricity to telegraphic communication.

On February 1, 1758, a Scotchman, Charles Marshall, of Paisley, then resident at Renfrew, published in the *Scots Magazine* a full and clear description of a practicable electric telegraph, and suggested the coating of his wires with an insulating material; and he may be therefore considered, in a sense, the inventor of the telegraph.

The first direct experiment appears to have been made by Lesage, who, in the year 1774, established in Geneva an electric telegraph, consisting of 24 metallic wires, well insulated from each other and each in communication with a small pith-ball electrometer, which could be diverged by an electrical machine, and caused to point to a letter or any other conventional signal. A few years later, in 1787, M. Lomond (*Young's Travels in France*, vol. i. p. 212) suggested the employment of a pith-ball electrometer; and in 1794, Reusser, a German, invented a telegraph in which signals were transmitted by electric discharges sent through strips of tin-foil, in which were breaks so arranged as to represent letters which became illuminated by the discharge (as represented in Fig. 29, p. 34). Cavallo, in his *Treatise on Electricity*, published in 1795 (vol. iii. p. 285), proposed to transmit signals by the inflammation of various combustible or detonating substances by the discharge of a Leyden phial; and, in 1787, Betancourt tried similar experiments in Spain, succeeding in stretching a line in the air over a space of twenty-seven miles, between Madrid and Aranjuez. He employed a battery of Leyden jars, and received signals by observing the divergence of suspended pith-balls.

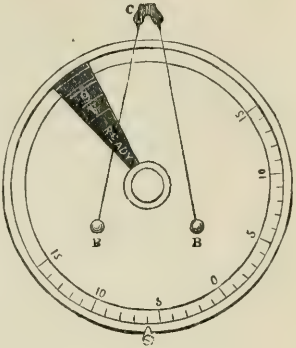
(226) **Ronalds' Electric Telegraph.**—This was invented in 1816, and fully described by the inventor in 1823.

A circular brass plate (Fig. 319), divided into 20 equal parts, was fixed upon the seconds arbor of a clock which beat dead seconds. Each division was marked by a figure, a letter, and a preparatory sign. The figures were divided into two series, from 1 to 10, and the letters were arranged alphabetically, leaving out J, Q, W, X, Z.

Before and over this disc was fixed another plate, capable of being occasionally moved by the hand round its centre, which had an aperture of such dimensions, that whilst the disc was carried round by the motion of the

clock, only one of the letters, &c., could be seen through the aperture at the same time : for instance, the figure 9, the letter V, and the sign 'Ready, are now visible through the aperture in Fig. 319. In front of this pair of plates was suspended a pith-ball electrometer from a wire *c* which was insulated and communicated with a cylindric electrical machine of only 6 inches in diameter, and with a wire 525 feet long, which was insulated in glass tubes, surrounded by a wooden trough filled with pitch, and buried in a trench 4 feet deep in the ground.

Fig. 319.



Another similar electrometer was suspended in the same manner before another clock similarly furnished with the same kind of plates and electrical machine. This second clock and machine were situated at the other end of the buried wire, and the clock was adjusted to go as nearly as possible synchronously with the first. Hence it is evident that, when the wire was charged by the machine at either end, the electrometers at both ends diverged. When it was discharged suddenly at either station, they both collapsed at the same instant ; and when it was discharged at the moment when a given letter, figure, or sign on the lower plate of one clock appeared through the aperture, the same figure, letter, or sign appeared also in view at the other clock ; and thus by such discharges of the wire at one station, and by noting down the letters, figures, or signs *in view* at the other, any required words could be spelt and the figure transmitted.

Such are the leading principles of this invention, which is characterised by great ingenuity. It does not appear, however, that Ronalds ever tried to work his telegraph at greater distances than 525 feet. On communicating his invention to the Admiralty, he was informed '*that telegraphs of any kind were then wholly unnecessary, and that no other than the one in use would be adopted*' (see his pamphlet, p. 24).

One of the most interesting points in connection with Ronalds' invention was his early knowledge of 'static induction,' which even at that period he recognised as an adverse element in the question of rapidity of communication. He says—

'Yet I do not contend, nor even admit, that an *instantaneous discharge* through a wire of unlimited extent would occur in all cases.'

And recurring to the subject further on he says—

'That objection which has seemed to most of those with whom I have

conversed on the subject the least obvious, appears to me the most important, and therefore I begin with it, viz. the probability that the electrical induction which would take place in a wire enclosed in glass tubes of many miles in length (the wire acting like the interior coating of a battery) might amount to the retention of a charge, or at least might destroy the suddenness of the discharge, or, in other words, might arrive at such a degree as to retain the charge with more or less force even when the wire is brought into contact with the earth.'

(227) **Sömmering's Electro-chemical Telegraph.** — In this invention, described in 1812, an attempt was made to communicate signals by the decomposition of water by the voltaic pile. With this view, 35 gold pins were passed through the bottom of a glass vessel containing acidulated water, each pin corresponding to one of the letters of the alphabet, or to one of the ten numerals. Each pin was connected by an insulated copper wire of any required length, to one of 35 plates fixed transversely on a wooden bar, and through the front of each of the plates there was a small hole for the reception of two brass pins, one of which was connected with the positive, and the other with the negative pole of a voltaic pile. Each of the 35 plates was arranged to correspond with one of the 35 gold pins in the glass reservoir, and was lettered accordingly. When thus arranged, the two pins from the pile were to be held one in each hand, and the two plates being selected, the pins were to be put into their holes, and the communication thus established. The gas evolved at the two distant corresponding points at the same instant, could be made to indicate every letter and numeral in accordance with certain rules. By varying the amount of gas given off at a given time, and by varying also the periods of time, the number of wires might be reduced from 35 to 2, and the construction of the telegraph thus much simplified. Schweigger proposed to diminish the number of signals by employing two piles, one considerably stronger than the other, sometimes using one, sometimes the other, and at other times both combined.

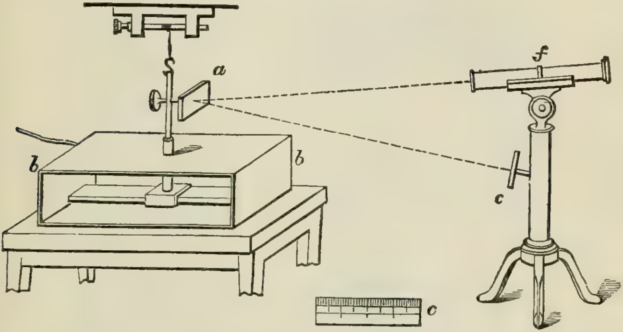
A proposition to employ the voltaic pile to indicate signals was also made in 1810, by Coxe, of Philadelphia (Thomson's *Annals of Philosophy*). He gives two methods—one by the decomposition of water, and the other by that of metallic salts.

(228) **Electro-magnetic and Magneto-electric Telegraphs of Schilling, Gauss and Weber.**—Shortly after the discovery of electro-magnetism by Oersted, in 1819 (147), Ampère pointed out to the Royal Academy of Sciences of Paris the possibility of constructing an electric telegraph with magnetic needles, surrounded by coils of wire; and in 1832 Baron Schilling exhibited before the Emperor Alexander of Russia an electric telegraph, constructed of a certain number of platinum wires insulated and bound

together with a silk cord, which set in motion, by means of a key connected with a voltaic pile, five magnetic needles placed vertically in the centre of a coil. The motion of one of these needles at the commencement of the signalling caused a leaden weight to fall, the concussion of which set in action a clock alarum.

Gauss and Weber, in 1835, employed the magneto-electric machine to give motion to the magnetic needle, which was enclosed in a coil composed of 3,000 feet of wire. By means of a commutator, the needle could be deflected in either direction and its movements were observed with the aid of a lens. This telegraph was actually worked at a distance of one mile and a quarter.

Fig. 320.



(229) **Steinheil's Sounding Magneto-electric Telegraph.** —This instrument, which was at work in July 1837, was fully described by its author in a communication to the Academy of Sciences, September 10, 1838. It was a printing and sounding telegraph, and was worked, like that of Gauss and Weber, by the magneto-electric machine; only one wire was employed, the *earth* being used to complete the circuit. To communicate signals by sound, Steinheil used two bells of different tones, either of which could be struck at pleasure by the needles; and to make a permanent record of a signal, dots were made on paper moved by machinery in front of the needles, each of which was furnished with a little tube containing ink.

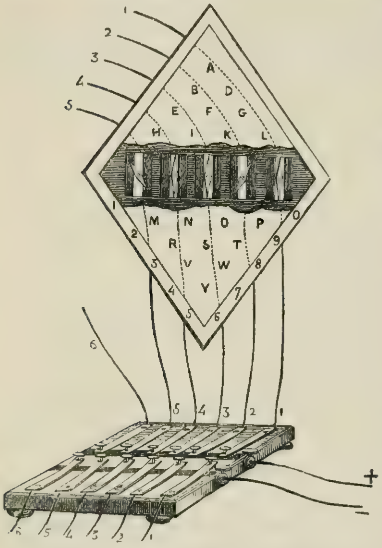
This telegraph was worked through 12 miles, and with 8 stations in the circuit; its invention was a great step in the advancement of electric telegraphing, since it established the fact of the sufficiency of the earth to complete the circuit.

(230) **Cooke and Wheatstone's Five-Needle Telegraph.**

—This instrument, the patent for which was sealed June 12, 1837, is shown in Fig. 321, and was thus described by Wheatstone in his examination before the Parliamentary Committee on Railways:—

'Upon a dial are arranged 5 magnetic needles in a vertical position; 20 letters of the alphabet are marked upon the face of the dial, and the various letters are indicated by the mutual convergence of two needles when they are caused to move. These magnetic needles are acted upon by electrical currents passing through coils of wire placed immediately behind them. Each of the coils forms a portion of a communicating wire which may extend to any distance whatever.

Fig. 321.



'These wires at their termination are connected with an apparatus which may be called a communicator, because by means of it the signals are communicated. It consists of 5 longitudinal and 2 transverse metallic bars fixed in a wooden frame; the latter are united to the poles of a voltaic battery, and, in the ordinary condition of the instrument, have no metallic communication with the longitudinal bars, which are each immediately connected with a different wire of the line; on each of these longitudinal bars 2 stops are placed, forming together 2 parallel rows. When a stop of the upper row is pressed down, the bar upon which it is placed forms metallic communication with the transverse bar below it, which is connected with one of the poles of the battery; and when one of the stops of the lower row is touched, another of the longitudinal bars forms a metallic communication with the other pole of the voltaic battery; and the current flows through the two wires connected with the longitudinal bars to whatever distance they may be extended, passing up one and down the other, provided they be connected together at their opposite extremities, and affecting magnetic needles placed before the coils which are interposed in the circuit.'

In a patent taken out shortly afterwards, the instrument had *four* needles with *five* wires. The improvement was that each needle, by its left and right movements, indicated two letters, whilst

in combination with one of the remaining needles it indicated another letter. The arrangement of the letters was different. The number of needles was afterwards reduced to *two*, and finally to *one*.

(231) **Cooke and Wheatstone's Single-Needle Telegraph.** —This instrument, which was patented May 6, 1845, is shown in Figs. 322 and 323. It is essentially composed of a single multiplier, with an indicator fixed vertically on a horizontal axis, and

Fig. 322.

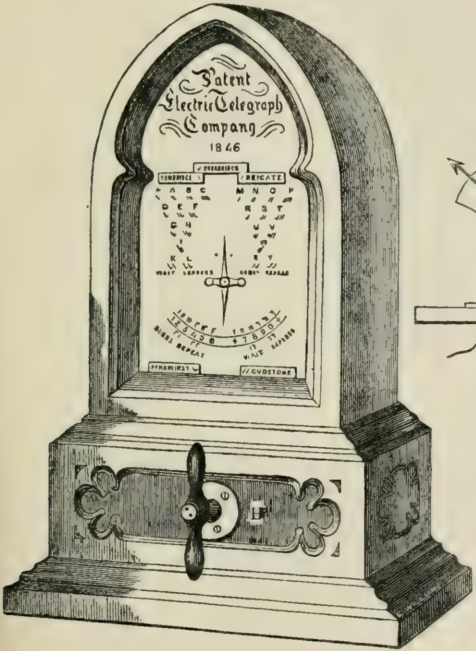
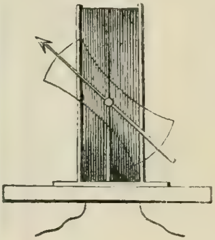


Fig. 323.

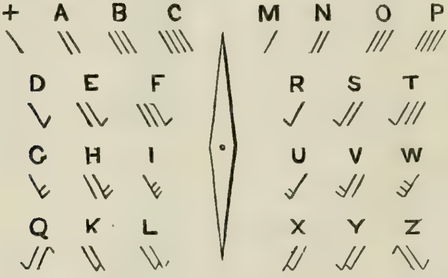


moving in front of a dial-plate. This indicator may be either a light strip of wood or a magnetic needle; if the latter, its poles must be in a reversed position to those of the needle in the bobbin. When the voltaic current is sent through the coil, the needle is deflected to the right or to the left, according to the direction in which the current passes. The alphabet is situated both on the right- and the left-hand side of the needle; some letters require

four movements of the needle, but the last motion which completes the indication of a letter situated on the right-hand side is always a movement to the right; in like manner, the last motion which completes the indication of a letter on the left side is always a movement to the left. For example, the letter W is indicated by four motions of the needle, three to the left and one to the right; the letter L also is indicated by four motions, to the right and then to the left, then again to the right, and finally to the left.

The code of signals formerly used with the single-needle telegraph is shown by the following diagram; and, bearing in mind that the deflections of the symbols for each letter commence in the direction of the short marks and end with the long ones, it will be seen that the deflections of a single needle may be made to denote all the letters of the alphabet:—

Fig. 324.



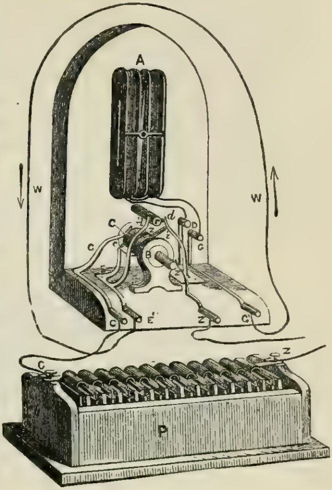
The numerals are inscribed on the dial underneath the needle, and are indicated by the movements of its lower half. For example, the figure 4 is designated by the motion of the lower extremity, once to the right and once to the left; the figure 9 by a movement once to the left and once to the right, and so on.

The alphabet for the single needle has latterly been changed, and it is now assimilated to the Morse code.

The internal mechanism of the telegraph is exhibited in Fig. 325. A is the bobbin, in the interior of which is placed either a single magnetic needle in the form of a rhomboid $1\frac{1}{8}$th inch long by $\frac{7}{8}$ths of an inch broad, or, which Walker suggested, several highly magnetised short needles firmly secured on either or both sides of a very thin ivory disc. The exterior or index needle is about three inches long. The frame of the coil is made of copper, wood, or ivory; it is screwed to a plate of varnished copper against the side of the telegraph case. The copper wire surrounding the bobbin A

is about $\frac{1}{100}$th of an inch in diameter, and is well covered with cotton or silk; one end of the wire from the right-hand bobbin is in contact with the screw G, which by means of a metallic strap is connected with the screw G′, secured on the base of the apparatus; the other end of the wire on the left-hand bobbin is in contact with another screw D, supported by a strip of brass which is fixed to the bar; and from this brass plate there rises an upright stiff steel spring *d*, which presses strongly against a point attached to an insulated brass rod *r* screwed against the side of the case; on the opposite side of this rod is another point against which a second stiff steel spring *d′* presses; this spring is attached to a brass plate E, terminated by a binding screw E′; E′ therefore is the screw terminal of the wire from the left-hand coil.

Fig. 325.



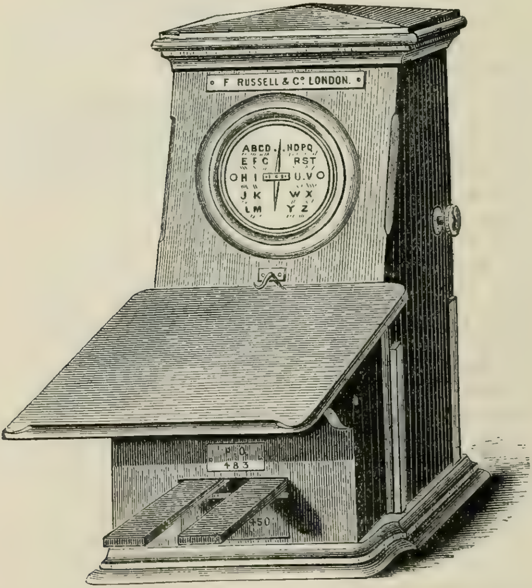
If G′ and E′ be now connected by a wire W, the current will flow from G′ through G into the right-hand coil, out from the left-hand coil to D, thence through *d r d′* to E, and from the terminal screw E′ round the wire circuit back to G′; and if the wire from G′ proceed *up* a line of railway, and the wire from E′ *down* the line, the circuit being complete throughout, the needle in the bobbin A will be deflected by a current proceeding from any station on the line, and thus signals will be communicated.

Battery contact is broken, and the direction of the current reversed, by the action of the springs *d d′*, in the following manner: —B is a boxwood drum movable by a handle seen at H, in the front of the base of Fig. 322. Round either end of this drum are fixed the brass caps C and Z; the caps do not touch each other, a disc of boxwood being between them. Into these caps are screwed the steel projecting pieces C′ Z′, which become the poles of the battery, Z′ being connected with the zinc end and C′ with the copper end; a wire C from the copper end of the battery conveys the current C′ C′, and a wire from the zinc end along Z, to a steel

spring which touches z, the continuation of the Z end of the box-wood cylinder.

Now on moving the drum by the handle H (Fig. 322), the steel spring d will be raised from its corresponding point on r; the circuit will thus become broken, and by continuing the motion of the drum, the wire C will come into contact with the spring below it, and thus there will be a battery pole at either end of the drum, and signals will thus be made on the dial, and on all the instruments connected with it. The connections are made in such a manner, that when the handle is turned to the right the needle moves to the right. The exterior or indicating needle is always placed with its N pole *upwards*; that within the coil with its N pole *downwards*; so that, in accordance with Oersted's fundamental law (147), looking at the face of the instrument, if we see the upper

Fig. 326.

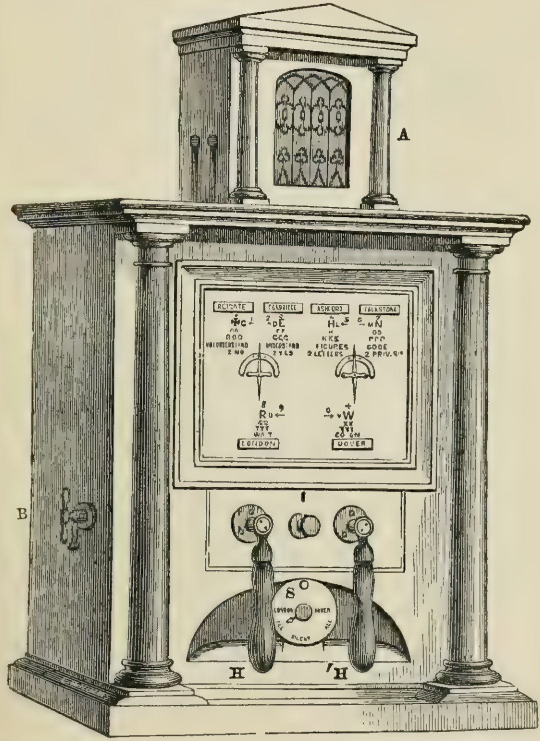


part of the needle moving towards the right, the spectator may be sure that the current is ascending in that half of the wire which is nearest to him.

The single-needle instrument at present in use in the Post

Office has, instead of a handle, as in the figure on p. 413, two keys or pedals, resembling in shape the keys of a piano, and which are termed the right and the left key; the former is depressed to make the upper point of the needle incline to the right, and the latter (or left key) is depressed to produce a movement of the needle in the opposite direction. As both hands are employed in

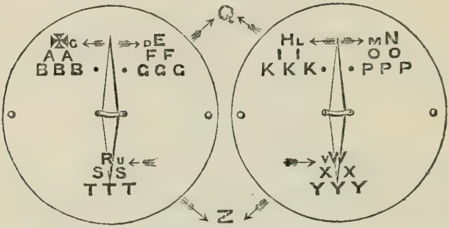
Fig. 327.



the manipulation of the pedals, a message can be sent at greater speed by this description of instrument than by that represented in the other figure (322). A similar instrument, but with a drop handle like one of those shown in Fig. 377, is largely used by railway companies in England.

(232) **Cooke and Wheatstone's Double-Needle Telegraph.**—This instrument, which was in general use for railway service in this country, is merely a combination of two single-needle instruments; it is represented in Fig. 327. On the top of the case is the alarum A, which is worked by the handle B. H H′ are the handles by which the two needles are manipulated. The internal mechanism is precisely similar to that of the single-needle apparatus. The alphabet used will be understood from Fig. 328, which represents

Fig. 328.



the face of the instrument with its two needles. The letters of the alphabet are ranged from left to right, as in the ordinary mode of writing, in several lines above and below the points of the needles, the first series, from A to P, being above, and the second series, from R to Y, below.

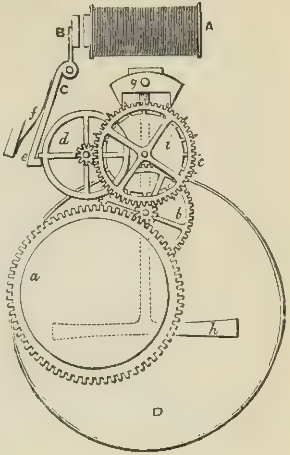
The sign + indicating the termination of a word is designated by a single movement of the left needle towards the left; the same signal is given when the receiver does not understand his correspondent's message. The signalling of the letter E signifies that he does understand. The double-needle instrument involves the employment of two wires; and though it is certainly quicker in action than the single-needle, it is not so superior to it as to justify the use of two wires. Hence it is gradually being replaced by the single-needle, and in a very short time scarcely any will remain in use except as curiosities. It has not been introduced into any other country besides England.

(233) **Alarums.**—1. *Worked by Clockwork.*—An instrument of this kind is shown in Fig. 329.

A is an electro-magnet; B an armature of soft iron, which is attracted by A, and retained as long as the voltaic current circulates round the bobbin. This armature is prevented from coming into actual contact with the pole of the electro-magnet by means of two little copper studs, tipped with ivory, inserted in its face; this is necessary, because, as soft iron does not lose the whole of its magnetism when the battery circuit is broken, permanent

adhesion would otherwise ensue. The armature is mounted on the short arm of a lever C, carrying at the other end of the arm a short projecting piece *e*, which, catching in a stop in the circumference of the wheel *d*, prevents it from moving. The armature is brought back to its normal position when the attraction ceases, by the small spring *f*, which presses against the long arm of the lever. Of the clockwork contained in the barrel, only the principal pieces are shown in the figure; the cogwheel *b* is connected by a pinion with the cogwheel *a*, which works *i*, and this again gives motion to *d*, which carries the stops. The anchor escapement *g* works on the wheel *i*, and on the axis of the same wheel is placed the double-headed hammer *h*.

Fig. 329.

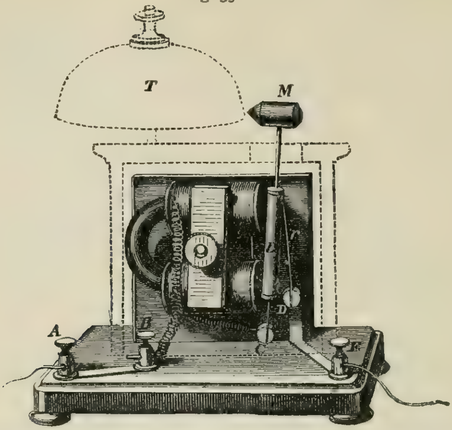


On completing the battery circuit, the armature B is attracted by the electro-magnet, the long arm of the lever C moves to the left, and the wheel *d* being then set at liberty, the mainspring in the barrel, which is kept constantly wound up, sets it in motion, and the hammer is instantly put into rapid vibration, striking alternately the opposite sides of the bell D; the ringing is kept up as long as the circuit is closed, but the moment it is broken, the armature is detached by the spring *f*, and the catch is again pressed into its place by the wheel *d*. It is not the voltaic current that rings the bell, but the mainspring in the barrel; all that electricity does is to disengage the catch; and there is no greater difficulty, therefore, in ringing a large bell than a small one.

2. *Worked by the Direct Action of the Voltaic Current.*—An instrument of this kind is shown in Fig. 330. Its action is very simple. The armature L of the electro-magnet is a hollow cylinder fixed on a steel spring D, and furnished with a hammer M, which strikes the bell T; a spring *r*, communicating with the earth by the binding-screw E, touches L when it is in a state of rest. A current from the line wire passes from A to B, traverses the coil of the electro-magnet, the spring D, the armature L, the spring *r*, and so to the earth; but, during its passage, L is attracted to the electro-magnet, the contact with *r* is broken, and the current ceases; L then falls back into contact with *r*, and the operation is repeated. In this manner a succession of blows are struck on the bell by the hammer M. There are many other forms of electrical bells, differing

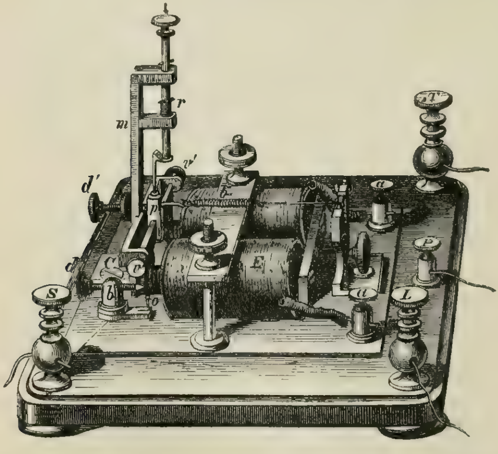
in construction, but they are all founded on the same electric principles.

Fig. 330.



A considerable force of current is required to work an alarum of this description, and on long lines a *relay* magnet is employed in

Fig. 331.



connection with it. This arrangement will be understood from an inspection of Fig. 331.

The current from the distant station passes from L through the coils of the electro-magnet, and so to the earth at T; the armature p is attracted, and the contact is made which puts in action the local battery; but at the same instant the button I is released, and starts up under the influence of the spiral spring r, and thus leaves a permanent record of the bell having been rung. This system is used when many wires from distant stations arrive at the same office; each wire has its relay, and there is but one alarum-bell; the relays are all arranged in a box having holes in the lid corresponding with the buttons; these start up into view when a current circulates through the electro-magnet coils, and designate the particular stations which wish to communicate.

(234) **Railway Signal Instruments.**—On the South-Eastern Railway, on which the alarum or '*Train Signal Bell*' has been used since December 1851, there are at the present time about 822 instruments in daily and constant use for the sole purpose of signalling trains on the 355 miles of which that railway consists. There are also 144 double-needle and single-needle speaking instruments. In an excellent article on 'Train-Signalling in Theory and Practice,' by Mr. Charles V. Walker, F.R.S., Telegraphic Engineer to the South-Eastern Railway Company, the laws of train-signalling are thus illustrated (*Popular Science Review,* April 1865):—

'Taking the simple case of a railway like the Ramsgate-Margate, for instance, having two pairs of rails, an *up* line and a *down* line, with a signal-station at each, but no intermediate station; the fundamental law is, *two trains or engines are not to be allowed to run on the same line between two signal-stations at the same time.* In order to carry out this important regulation, upon which the security of those that travel so largely depends, every train or engine must be signalled *out* to the next station before it *leaves* or *passes* a station, so that, when the business of the day, for instance, commences, station B knows that train No. 1 is asking permission to come to him from station A; and, to prevent all misunderstanding, the train or engine must not be started or allowed to pass until the next station has taken the *out signal.* It is not enough for the first station to *give* the signal, the other station must *take* it, for no signal given by one station is complete until taken by the other station repeating it, by which process a clear understanding is established between the two signallers, and the precise signal *sent* by one is *received* by the other.

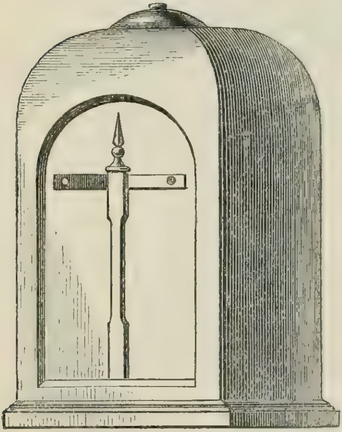
'The next rule is,—*Every train or engine that arrives at, or passes a station, is to be immediately signalled back in to the last station*; and it follows, from what has been already stated, that no second train or engine is to be allowed to follow until the *in* or arrival signal of the previous train has been taken—that is to say, has been repeated back blow for blow.'

In each signal-box a battery with the proper number of cells is mounted, a bell is set up, and a ringing key, mostly detached from the bell for convenience of access, is firmly fixed, and *one* telegraph

wire is extended from station to station. The signalmen are not required to look after the apparatus, which is so simple that it almost takes care of itself. All they have to do is to make and enter the signals. In the case of an intermediate station, a pair of bells of different tones are provided. They are placed on either side of the box, each being at the side nearest the station with which it is in communication. The signalman, by the *sound* of the bell, by the direction from which the sound comes, and by the number of blows heard, knows on the instant whether it is a train coming; or one gone and safe in; and which train.

(235) **Electro-magnetic Semaphores.**—Where the trains up and down a railway are many in number, it is found necessary to combine a visible with an audible signal, the former showing at a glance the actual state of the line, i.e. whether or not the lines in either direction are free from trains. The instrument by which visible signs are indicated is called a 'semaphore' (see Fig. 332). On the Charing Cross Railway the electro-magnetic semaphores are miniature resemblances of those used on the railway; they are provided with a *red* arm on the left side, and a *white* arm on the right side, each capable of being moved by the electric current. They are placed in the right- and left-hand corners of the signal-box, and the regulations for working them are such that the arms at all times indicate the state of the line.

Fig. 332.



Looking *towards* a semaphore, whether actual or electro-magnetic, the red and left arm has reference to trains receding; the white and right arm to trains approaching. When an arm is up, it indicates that a train is on the line, and when down, that a train is not on the line. The principle upon which the electro-magnetic semaphores are connected up and arranged on the Charing Cross Railway is, that 'each station can put up or down the white arm only at his own station, and the red arm only at the other station.' No signalman has power to alter the position of his own red arm; it

is put up behind a train by the next station, and put down when the train is in at that station.

The motions of the arms of the electro-magnetic telegraph semaphore are produced in a very simple manner. A couple of bar magnets are so mounted in a movable system in relation to the two poles of an electro-magnet that the action of the latter on the four poles of the magnet is combined to produce motion in one direction with one current of electricity, and in the reverse direction with the reverse current, and these motions are transferred to the arms of the semaphore.

(236) **Preece's Block-Signal Instruments.**—The first practical application of the semaphore signal to electric signalling apparatus was due to Mr. W. H. Preece who is the inventor of two systems of signal instruments, viz. a three-wire and a single-wire system. The peculiarity of these instruments, used for the special purpose of signalling trains, is their perfect assimilation in appearance and in manner of working to the outdoor signals with which the men are so well acquainted. In the three-wire system one wire is used for *down* traffic, the second wire for the *up* traffic, whilst the third is devoted to the calling apparatus in connection with a bell. The apparatus in the three-wire system comprises at each end a set consisting of a semaphore (the block signal), the switch or key which actuates it, the bell, and the bell-key.

Figs. 333 and 334 show the electrical connections and the internal arrangements of the several parts of the apparatus representing the instruments to be used, at one end of a section of the line, for regulating both the up and down traffic. In Fig. 334 will be seen the internal arrangement of the various parts of the apparatus.

'A pair of electro-magnets H, a rocking lever D W, connected at one end by a wire rod R to the indicating arm, and at the other to the armature in front of the cores of the electro-magnet. This lever is pivoted at E, and is so weighted by the movable weight W that it shall normally—that is, when not otherwise influenced by a passing current—rest on the cock F, in which position the arm stands at *Danger*. On passing a current through the coils, the armature is attracted, and the lever D W raised, carrying with it the rod R, which lowers the arm to the *All clear* position. It will thus be seen that whilst the instrument is at rest, or in its normal condition, the arm is at *Danger* and the rocking lever in contact with the lower stud F, and that when a current is passing the arm is lowered and the lever in contact with the stud G. The details of the bell are shown also in Fig. 334. K is an electro-magnet, M the armature, with rod O carrying the bell-hammer at its extremity; L is a magnetised needle fixed upon the spindle N, to the other extremity of which is attached a shield carrying the words *Off* and *On*, so arranged that when the needle L is drawn over towards one pole of the electro-magnet, as it would be, say, by a negative current, the word *On* shall be brought up to the aperture in the face of the bell, whilst the arma-

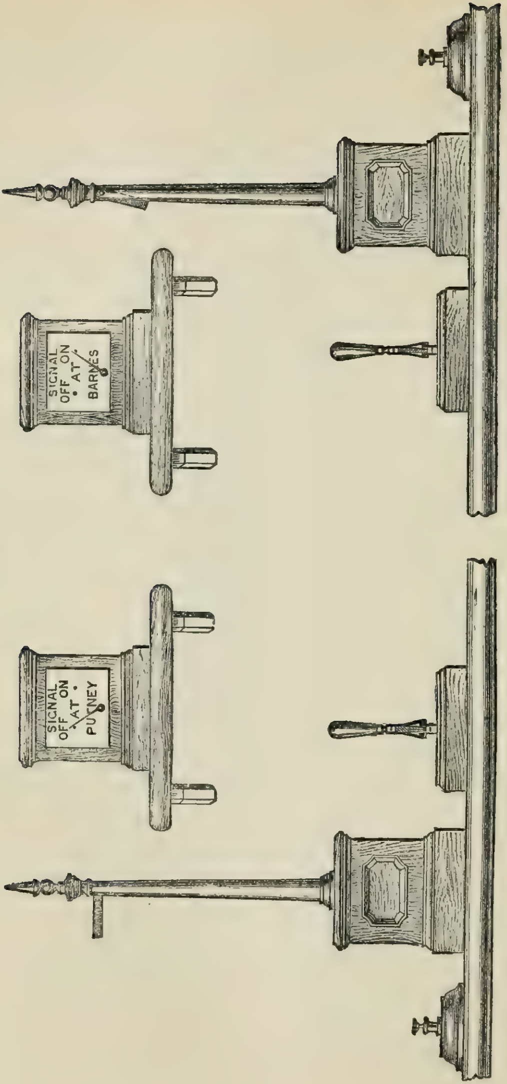
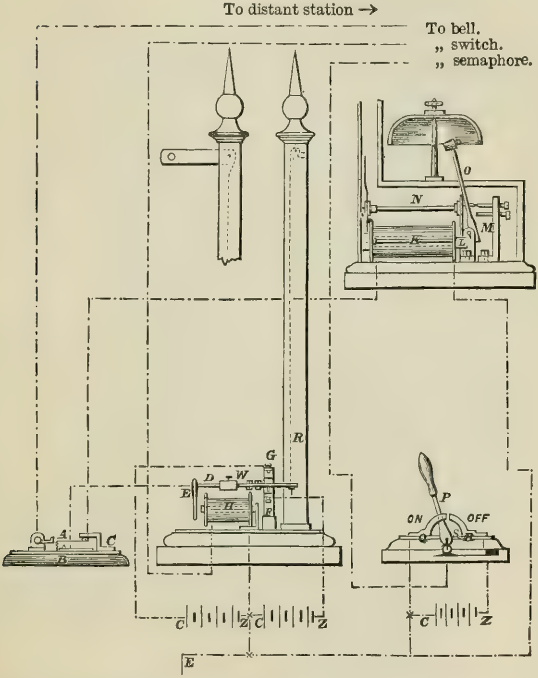


Fig. 333.

ture is at the same time attracted towards the coils and a stroke struck on the bell. In like manner a positive current would carry the needle to the opposite pole, displaying the word *Off* at the aperture and at the same time striking the bell. Thus a change in the current, positive to negative, or negative to positive, will produce a change in the indication. Any number of currents sent will give a similar number of beats on the bell, but no change will take place in the indicator unless there is a change in the current or in the direction in which the current passes through the coils. The

Fig. 334.

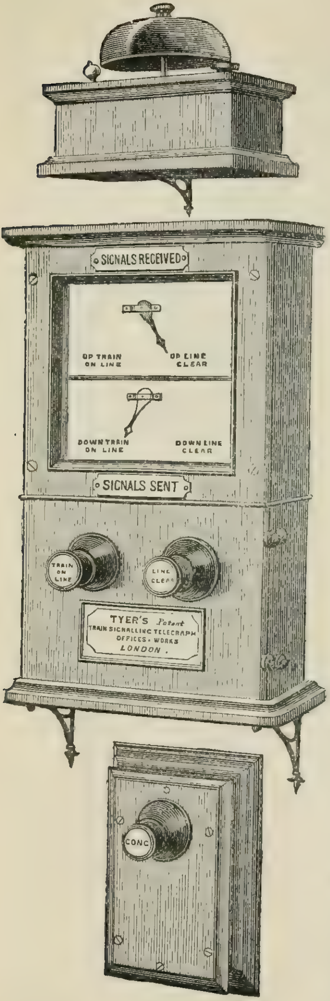


object of the indicator is to repeat the condition, or rather the position, of the semaphore arm at the distant station. The number of the beats represent certain signals.

'The lever or handle of the switch P is arranged to move freely upon its centre S, but is provided at its extremity with a small steel roller for traversing a spring with a double inclined plane, the object of which is to keep it (the lever) in whichever position it may be placed, whether in the direction of *On* or *Off*. The semicircular piece Q R is divided in the centre,

and each portion so slotted as to admit of the handle moving within it to the angle represented in the figure. The handle is provided with springs, which on either side press firmly against the segments Q R, so as to make good contact therewith.

Fig. 335.



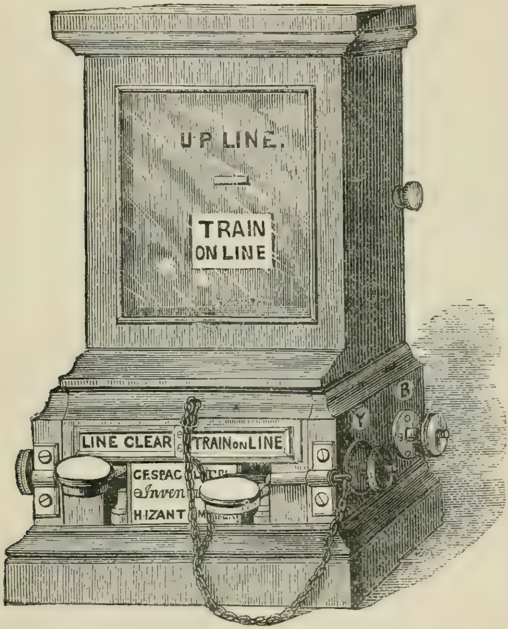
'In the bell-key A is a strong lever, free to move between the stop-pieces B C, but held in contact with the latter when at rest by the spiral spring placed below it. It is only on pressing the knob of the bell-key that the lever A is brought into contact with the lower contact B.

'The electrical connections are clearly shown in Fig. 334. The line-wire from the bell at the distant station joins the bell-key at A, and is there in contact with the stud C; thence it proceeds to the coils of the bell and to earth. The line-wire from the switch at the same station is merely in connection with the coils of the semaphore, whence it goes to earth. The wire from the distant semaphore joins the switch at its lever P, and through it is either brought into circuit with the battery attached to the segment R, or put to earth through Q. The battery arrangement consists of one set in connection with the R or *Off* segment of the switch, and two sets in connection with the semaphore, the zinc pole of one set being connected with the contact F, and the copper pole of the other set being connected with the upper contact G.'

(237) **Tyer's Train-Signalling Telegraphs.**—A set of these instruments consists (see Fig. 335) of a signalling instrument with two indicators and two plungers, a bell or gong, and a plunger for actuating the distant gong. It is a single-wire system. The indi-

cators are coloured white and red, and are actuated by electro-magnetic apparatus brought into action by the pressure of one or other of the plungers 'Train on line,' 'Line clear.' Attention is called by the gong, and the number of beats designate various trains or signals. In the more recent forms of this system a 'semaphore' is adopted instead of the ordinary indicators shown in the figure. The electro-magnets used differ from the ordinary form, inasmuch as that the iron cores employed are not of soft iron, but of *steel*, in which

Fig. 336.

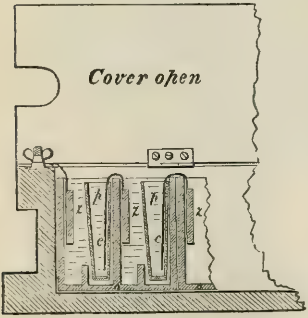


a large amount of residual magnetism is retained. The indicators are attached to soft iron needles in connection with the steel cores, and are therefore magnetised by induction, and retained in their position, which is only changed by a current of electricity of an opposite kind to the preceding, producing at once a reversal of polarity of the electro-magnet. It will be seen, therefore, that the needles and indicators are held in the same position until the current is reversed.

(238) **Spagnoletti's System.**—This is a three-wire system, and consists of an instrument, a bell, and a bell-key. The signalling instrument was originally similar to the ordinary Cooke and Wheatstone needle, but, instead of indicating by a needle or pointer, the indication is made through an aperture by means of a card fixed on the end of the armature carrying the words 'Train on line,' 'Line clear,' the former on a *red* ground, the latter on a *white* ground (Fig. 336). Signals are made by means of a pedal arrangement, in action similar to an ordinary key, the two pedals sending reverse signals. When a signal is sent, the pedal is kept down by inserting a pin in a groove, which prevents the pedal from rising. In order to avoid demagnetisation of the needle, in consequence of lightning or other causes, Mr. Spagnoletti has introduced a method of keeping the needle magnetised by induction, a plan which has proved quite successful.

(239) **Telegraph Batteries.**—The batteries originally used to work our English telegraphs were composed of amalgamated zinc and of copper plates, 4½ inches long by 3½ inches wide, the zinc being three-sixteenths of an inch thick. The plates were cemented water-tight on to stout teak-wood or oak troughs, each trough being from 15 to 30 inches long, and 5½ inches wide, and divided into 12 or 24 cells by partitions of slate. The plates, connected together by copper slips, were placed across the slate partitions, and the cells were filled to within an inch of the top with siliceous sand, which was then saturated with a mixture of 1 part of oil of vitriol and 15 parts of water. The number of cells used varied according to the distance between the stations; for short groups of 10 or 15 miles, 24 cells were employed; for distances from 40 to 60 miles, double that number. These sand batteries, though developing a powerful current of electricity when first charged, are very inconstant, and in almost every case have given way to a modification of the battery of Daniell, devised by Mr. John Fuller in 1853.

Fig. 337.



One form of this sulphate of copper battery used for telegraphic purposes in England is that known as '*Muirhead's or the chamber battery.*' A longitudinal section through one end of this battery

is shown in Fig. 337. The zinc plates are about 4 inches × 2 inches, the copper plate is about 4 inches × 3 inches. The porous cells, *p p*, are filled with solution of sulphate of copper; very dilute sulphuric acid is put in the outer cells, which are of white porcelain, and made in pairs. Five such pairs are enclosed in a strong box with a wooden cover. To check endosmose through the porous cells, they are greased, except on the portion which is opposite to the zinc plate.

Instead of sulphuric acid, a solution of suphate of zinc is used in the zinc cell; in this case it is not necessary to amalgamate the zinc plate, and there is little local action; but the sulphate of zinc must not be allowed to crystallise on the zinc plate, or it will stop the action of the battery. The saturated solution of the salt should be diluted with an equal quantity of water. Contact between the zinc plates and the porous cells should be avoided, as such tends to the deposit of metallic copper on the porous cell, and the consequent establishment of a local circuit.

Mr. Cromwell Varley in 1854 dispensed with the porous partition by placing plates vertically above one another, copper being at the bottom, and keeping the two solutions separate by their relative weights or specific gravities. Hence this form of battery is called the '*gravity*' form. It is, however, a wasteful form, for the solutions necessarily mix, and considerable local action ensues.

The battery used by Walker on the South-Eastern Railway to ring the signal-bells consists of gas carbon platinised, and amalgamated zinc, with dilute sulphuric acid.

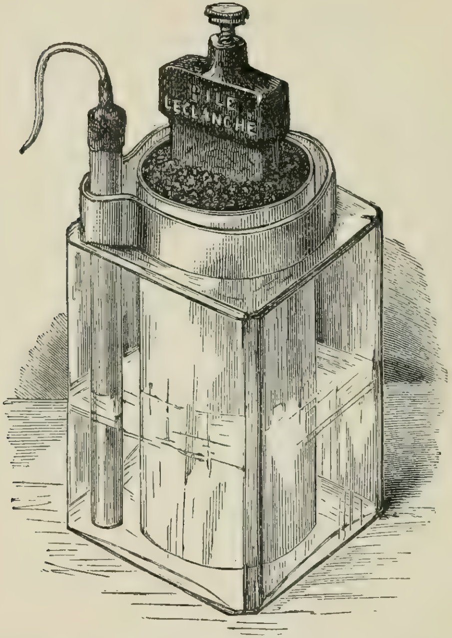
(240) **Leclanché Battery.**—This is a battery which of late years has very much supplanted the different forms of Daniell's cell, and is now largely used for all kinds of telegraphic purposes. It is the invention of M. Leclanché, of Paris, and possesses great merits, which are substantially proved by its large adoption. Fig. 338 explains the form of the battery. The outer glass cell contains the zinc element immersed in a solution of sal-ammoniac; the porous pot contains a plate of carbon surrounded by coarse grains of peroxide of manganese and carbon. Great difficulty was at one time experienced with the connection of the carbon plate, the lead top being frequently acted upon; but these difficulties have been overcome and the battery is now used for various purposes. It possesses very low internal resistance with great electromotive force. In working circuits of low resistance it soon polarises and runs down, but where the resistance is high this battery is found to work with great constancy and economy. It is much used in France, Belgium, and other countries, and is also very largely in demand by the railway companies of this country.

M. Leclanché says :—

'To get good results, the following precautions require to be taken :—

'A peroxide of manganese, very pure, and a good conductor of electricity,

Fig. 338.

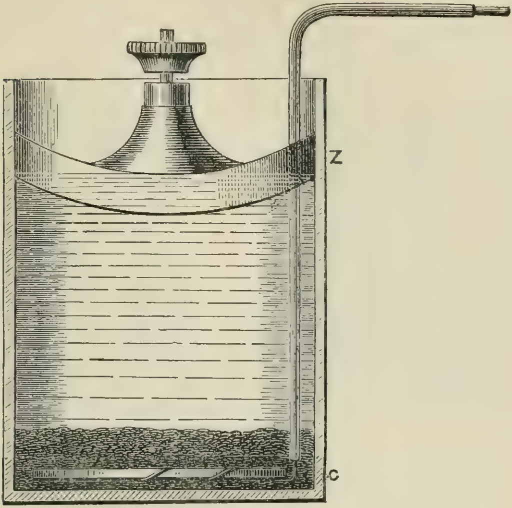


must be chosen. The best is that which is known under the name of *needled manganese*. It is crystallised, silky, and of a very distinct graphitoidical brilliance; if it has, in addition to those different characters, a certain hardness, it will possess a greater conducting power. To employ this peroxide, the gangue or vein-stone must first be removed, and the remainder broken up into coarse grains. Afterwards it is passed on a sieve to get rid of the powder, which done, an equal volume of crushed horn carbon is added. Thus a perfectly conducting mixture is obtained.'

(241) **Minotto Battery.**—This is a modified form of a Daniell, and its appearance may be seen in Fig. 339. It consists of a round glass or glazed earthenware jar, about five inches high; at the bottom is a disc of copper C, to which is attached an insulated copper wire projecting beyond the jar. The battery is charged

by placing on the copper disc about eight ounces of sulphate of copper, and above that a quantity of sand or sawdust, upon the top

Fig. 339.

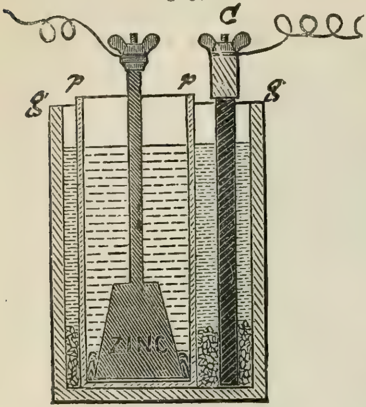


of which rests the thick circular zinc plate z. The sand or sawdust prevents the sulphate of copper rising to the zinc. Water is poured in until the sawdust is thoroughly moist. The electromotive force of this battery is remarkably constant; the internal resistance is from 10 to 20 ohms, varying with the quantity of sand and the manner in which it is packed. It is a battery largely in use, and in India its use is universal.

(242) **Fuller's Mercury Bichromate Battery.**—This is the most recent form of battery introduced for practical telegraphy, and whilst found to be of great electromotive force it is also very constant. Fig. 340 gives a section of the latest form of this battery. *g g* is a glass jar, in which is placed the porous pot *p p* containing the zinc plate; the negative element C is a carbon rod placed in the glass jar as shown. To charge the battery it is necessary to deposit in the glass jar about three ounces of bichromate of potass, and one ounce (or one measure) of mercury in the porous pot with the zinc element. The solution must consist of one part of sulphuric acid, and nine parts of water, in the glass jar with the crystals. The porous pot must be filled with water only.

Its electromotive force is double that of Daniell's, and its internal resistance about 2 ohms. It is stated that, with ordinary working, extra crystals will not be required for at least six months, and none need be used whilst the solution continues to be of an *orange* colour; but if it should have a *blue* tint, then crystals must be added. If the colour remains good, and the battery fails in power, then three or four ounces of pure acid should be added, and some of the solution from the porous zinc cell removed, refilling with water only. Fuller's battery is now being largely adopted by the Post Office and the railway companies.

Fig. 340.

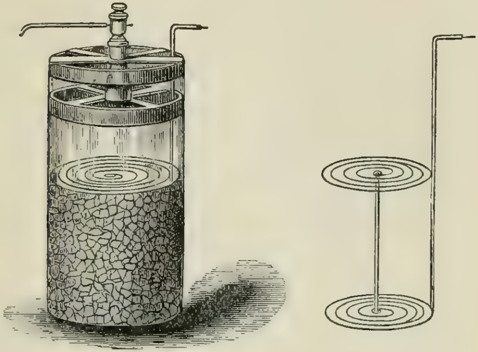


(243) **Callaud Battery.**—This battery was introduced into France by M. Callaud, and has subsequently been largely adopted in America. It is a *gravity* battery, pure and simple. The copper plate is placed at the bottom of the cell, in some in the form of a flat plate, in others with the corners turned down, to serve as legs and keep it slightly raised above the bottom of the jar, whilst occasionally a coil of copper wire is employed. The zinc has likewise more than one form. Sometimes it is star-shaped; at other times it is a perforated plate, and not unfrequently it is conically shaped on the lower surface, so as to prevent the bubbles of gas from adhering to it. Callaud proposed to vary the internal resistance of his cell by providing for the lowering or raising of the zinc plate at will. This has been proved to be useless.

(244) **Lockwood Battery.**—This battery is the invention of an American, and is largely employed in the United States. It is a gravity battery, and its general appearance is shown in Fig. 341. The copper element consists of two concentric coils of copper wire and an upright standard, formed of a straight piece of heavy copper wire, provided with nuts and washers at each end. An insulated wire is connected to the lower coil, and passed upwards through the jar to the succeeding zinc. Special stress, says Mr. Sivewright (*Journal of the Society of Telegraph Engineers*, vol. iv. 143), is laid upon the necessity of so arranging this that the outside of the copper coil

should run to the *right* of the insulated wire; and at the same time care must be taken that the coils are so placed that the outside of the lower coil runs to the *right*, and the outside of the upper coil to

Fig. 341.

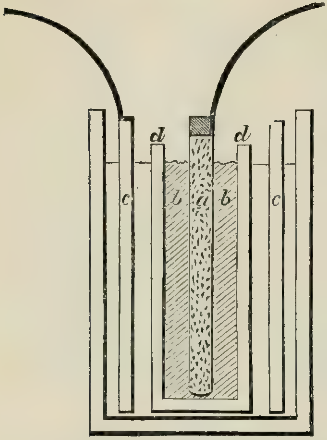


the *left*. This, it is stated, is essential to the proper action of the battery. The battery is charged with crystals of sulphate of copper. The zinc plate is supported on the top by a metal cross-piece.

(245) **Chutaux Battery.**—This battery is a one-liquid battery, the liquid consisting of $11\frac{1}{2}$ parts sulphuric acid, $5\frac{1}{2}$ bichromate of potash, 3 parts sulphate of soda, 80 parts of water. Each cell is composed of a cylindrical vessel, half the capacity of which is filled up with powdered carbon, in which a flat piece of graphite is embedded; whilst the other half is filled up by silver-sand, in which the zinc is also embedded. The arrangement of the cells is peculiar, and constitutes the principal feature of the battery: the cells are placed one above the other on shelves in two, three, or more rows; on the top of one cell is placed, also on a shelf, a glass balloon vessel, at the bottom of which is fixed a porous pot. The exciting liquid is first poured into this balloon, from which it percolates slowly through the porous pot, dropping on the first row of cells; then, the cylindrical vessel having itself a hole at the bottom, the liquid drops on the cells underneath; after having passed through these, it is finally received in vessels to be used again. A lengthened trial of this battery has proved it to be of great merit.

(246) **Marié-Davy Battery.**—This battery, which is shown in Fig. 342, has been much used in England, and is largely employed in France and on the Continent. The elements are zinc and graphite plates, excited by moistened bisulphide of mercury. The zinc plates are amalgamated, and the graphite plates are cut from the refuse of gas retorts and covered with a coating of powdered platinum by electro-chemical deposition. In the figure *a* is the platinised graphite, *b b* the bisulphide of mercury, *c* a circular zinc plate, *d* a porous cell. In Austria, for use in transport, the porous cell has been done away with and a mechanical obstacle, such as sand, substituted.

Fig. 342.



(247) **Electromotive Force of Batteries.**—According to Latimer Clark, the electromotive force of various batteries is as follows:—

Grove	100
Bunsen	98
Marié-Davy	76
Chloride of silver	62
Smee's (when not in action)	57
Daniell	56
Wollaston	46
Chloride of lead	30
Smee's (when in action)	25

Leclanché gives the value of his peroxide of manganese battery as superior to that of a Daniell battery:—

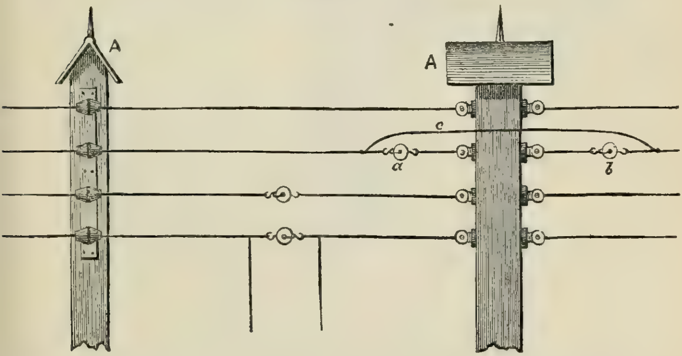
Sulphate of copper (Daniell)	= 1·000
Peroxide of manganese	= 1·382

(248) **Byrne's Pneumatic Battery.**—This battery has been specially devised with a view of providing the medical profession with a portable battery, capable of producing a considerable amount of heat, as required for cauterising. The negative plate consists of a very thin plate of platinum to which a lead backing is soldered,

and this is covered with a sheet of thick copper, also coated with lead, the whole being then covered with a non-conducting varnish, with the exception of the exposed platinum face. Two of these plates are arranged to face the zinc plate, as in Wollaston's form of cell, and the exciting liquid consists of 12 oz. of bichromate of potash, one pint of sulphuric acid, and five pints of water. By using such a mixture the sulphuric acid attacks the zinc, and the three atoms of very loosely combined oxygen exercise a depolarising effect, by absorbing the evolved hydrogen. A tube dips into the exciting liquid, and is so arranged that it conducts a current of air, from a small pair of bellows, against the face of the negative plate; by this means the current obtained from a given electromotive force is materially and wonderfully augmented.

(249) **Supports and Insulators for Overground Wires.**—The modes of sustaining and insulating telegraph wires formerly

Fig. 343.



adopted in England are represented in Figs. 343 and 344. Wooden posts, from 15 to 30 feet high, are fixed firmly in the ground at the rate of about 30 a mile; the upper part of each post is 5 or 6 inches square; it carries a wooden arm, which is separated from the post by discs or rings of brown delfware. The arm is secured to the post by an iron bolt and screw. On the face of the wooden arm four hollow double earthenware or glass cones are fastened by collars of iron; through these the wires pass, and are thus effectually insulated. Other forms of insulators are shown in Figs. 345, 346, 347, and 348. A contrivance for tightening the wires is seen at B (Fig. 344). The posts on which this apparatus is placed are much stouter than the ordinary sustaining-posts, and are fixed

at intervals of $\frac{1}{4}$ of a mile apart. To the upper part of the post are attached as many iron screws as there are telegraph wires, and

Fig. 344.

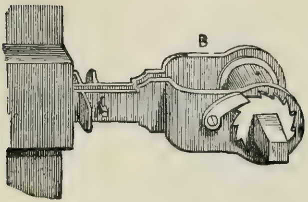
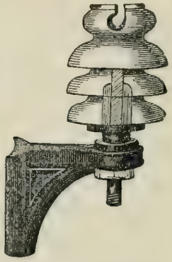


Fig. 345.

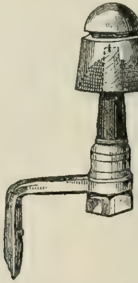
Fig. 346.



each screw carries a winder consisting of a grooved drum with a wheel and ratchet attached; the ends of the winder are insulated

Fig. 347.

Fig. 348.



from the post by discs of earthenware; *a* and *b* (Fig. 343) are two earthenware pulleys or *shackles*, each furnished with two hooks

Fig. 349.

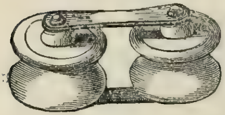
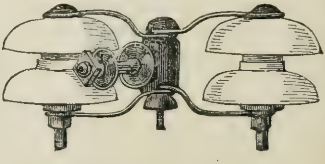


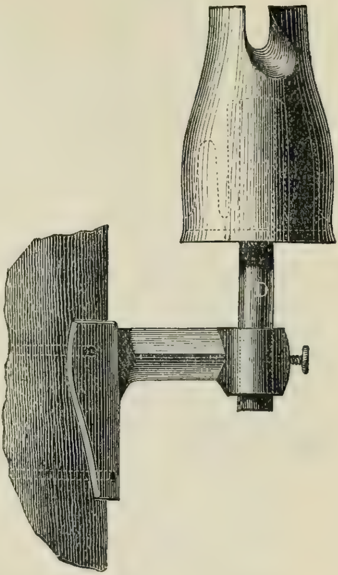
Fig. 350.



insulated from each other. The winding-post is thus seen to be out of the circuit, but the metallic continuity of the telegraph wire is secured by the thin wire *c*, soldered to the outside of each

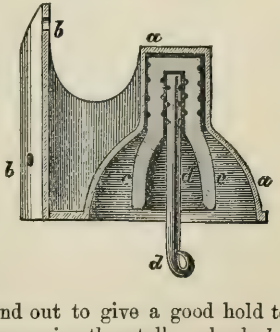
shackle. Fig. 349 shows the form of shackle usually employed for making a break in the line in order to introduce an instrument into the circuit, and Fig. 350 represents Bright's patent terminal insulator, which is largely used in over-house telegraphs. One or two insulators are attached to the bolt as required; when used as an intermediate support for long spans, or at bends in the line, two insulators are attached, as shown in the figure, and the conductor is completed by soldering a short wire to the line-wire at each side.

Fig. 351.



In 1856 Mr. Latimer Clark patented an insulator in which he increased the length of surface of the porcelain over which the current escapes, without increasing its section. He attained this by a double bell formed in one piece. The insulator is supported by a stalk D (Fig. 351) cemented into the interior of the inner cavity; the line-wire is carried through a deep groove on the top, and is fixed to the bell by a binding wire.

Fig. 352.

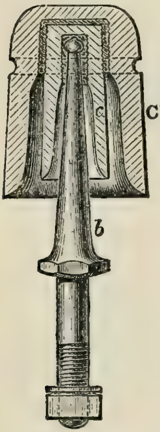


Another kind of line insulator is the strongest and most expensive of all. The first insulator of this kind was that made by Messrs. Siemens, of Berlin. It consists of a cast-iron bell *a a* (Fig. 352) with a flange *b b*, by which it is screwed against the post. Inside the bell is cemented a porcelain cup *c c*, ribbed inside and out to give a good hold to the cement. The cup *c c*, in turn, carries the stalk or hook *d d*

which supports the line-wire. The parts are put together, while hot, with a cement composed of sulphur and oxide of iron. As a further mode of insulation, the iron stalks or hooks are covered with vulcanite before being cemented in; sometimes the porcelain cup is replaced by a cup of vulcanite. These insulators are a little heavy, but their superior solidity and insulation are ample compensation, the iron cap forming at once a perfect protection against injury and a screen against the deposit of dew on the porcelain.

The insulator, according to *Preece and Sivewright*, 'which is in general use in England is of brown earthenware, and is shown in Fig. 353. It consists of two distinct and separate cups, *c* and c′, which are fitted into each other by means of a cement composed of equal parts by weight of fine white sand, Portland cement, and plaster of Paris. Into the inner cup *c* a galvanised iron bolt *b* is inserted, and fixed by means of a cement composed of

Fig. 353.



'5 parts by weight of clean river sand, sifted.
3 „ „ engine ashes (from an old engine fire-box).
2 „ „ fine resin.

'A groove is cut on the surface of the outside, and into it the line-wire is placed and firmly bound. This form of insulator combines several advantages, to which attention may briefly be drawn. Whatever current escapes from the wire in the groove must make its way over the entire surface of both cups before it can reach the bolt. By having two cups again greater reliance can be placed upon the quality of the earthenware; the two small pieces can be better burnt and vitrified than one larger portion; and the probability of flaws or faults occurring in such caps is very remote. At the same time, by means of this arrangement, one portion of the insulator is open to the cleansing action of the rain, which serves to remove any dust or dirt apt to adhere to it; whilst the other is kept dry, and in wet weather continues to offer considerable resistance to any escape of the current.'

No form of insulator, however, has been found to really overcome the tendency to get 'dirty,' and therefore less insulating, this tendency varying according to the nature of the country, and it is frequently found necessary to clean the insulators thoroughly. With the wires fixed this has been found a difficulty, especially

as the bolts frequently get immovably set. Mr. Cordeaux, of Birmingham, has suggested an improvement which facilitates these operations. He makes the insulator with a thread inside, so that it screws on to the bolt, and when necessary can be easily removed. It has been found so serviceable that the Post Office authorities are using it largely for the telegraph system.

The insulator much used in France is shown in Fig. 354. The iron hook by which the wire is suspended is cemented into the porcelain by a mixture of sulphur and colcothar. The

Fig. 354.

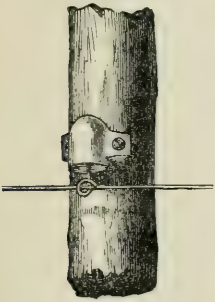
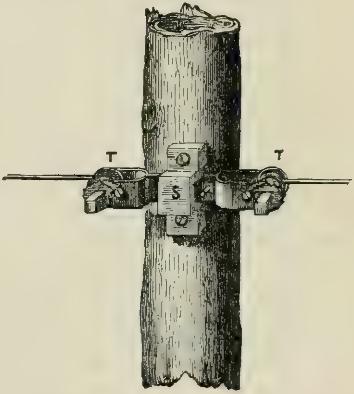


Fig. 355.



tigh'ening ratchet is shown in Fig. 355; it is made of galvanised iron, and one is fixed at every mile, the supports being of porcelain.

The insulator used in Germany is somewhat similar to that shown in Fig. 351. It is made of white porcelain. A somewhat similar kind is used in India. In Australia the *Oppenheimer* form —a modification of Fig. 351, which has a thread inside to screw it direct on the bolt, so as to save the use of cement—is used. In America green annealed glass is universally used, in form like that shown in Fig. 348. It also screws directly on to a wood pin. Glass was once largely used in England, but it was found too brittle.

Iron-hooded insulators have been partially used in localities peculiarly subject to stone-throwing; but, according to Culley (*Practical Telegraphy*, p. 60), coverings to insulators are not only useless but injurious.[1] They do not themselves insulate; they

[1] It is, however, necessary in certain Eastern countries to use iron-hooded insulators.

afford no protection in fogs or continued rain, for then every part becomes equally damp; they harbour spiders, which spin their threads over and among the wires; they hinder the drying of the supports, and prevent the rain from washing off the dust. Insulation is frequently improved by a heavy summer shower; but the insulation of the wire is never perfect, even in dry weather, and although the leakage may be very small at any given point, yet as the total surface exposed is as much as 220 square feet per mile of No. 8 wire, the loss of electricity by defective insulation may be very great. The best material yet known for insulation is ebonite, and if it should be found to bear exposure to the weather, it will doubtless be extensively used as a telegraph insulator. The next best substance is stoneware, which possesses the important advantage over glass that its affinity for moisture is much less.

There are two sorts of leakages to which telegraph wires are liable, one direct to the earth, which simply weakens the current, and which can be restored by additional battery power, the other a leakage into another wire, which causes great confusion in the working of the instrument, which is increased by an accession of battery power. These faults are technically called 'earth' and 'contact,' the former being contact with the ground, the latter contact with another wire. The latter is entirely obviated by placing the insulators upon a metallic post, or by connecting them by a wire to the earth, so that all the current which leaks over their surface may have a path provided which shall conduct better than the line-wire, and the extra current thrown into the circuit by the lessened resistance may be provided for by an increase of battery power.

The distance between telegraph poles in this country varies exceedingly, not only on account of the route adopted, but also on account of the number of wires required. In a straight line with but few wires the poles may be as few as 16 to the mile, but on canals, where the sinuosities are very frequent, the number often extends to 40 per mile, and the poles are frequently doubled, as may be noticed on the canals near London. The poles now in most frequent use are of fir, prepared with sulphate of copper on Dr. Boucherie's plan, or else creosoted in the ordinary manner; the latter is the more favourite plan of the two. The cross-arms carrying the insulators are of oak, and vary in length according to the number of wires to be carried. But it is often the custom, when a line of poles carries a number of wires—two on each arm—to vary the length of the arms, and have two sizes, placed alternately, so that one wire is not *immediately* under the next one above it. The distance between wires perpendicularly is greater abroad

than in this country, the result being that we suffer more from the induction between wire and wire.

Fig. 356.

(250) **Iron Posts.**—The iron post of Messrs. Siemens is coming very generally into use abroad.

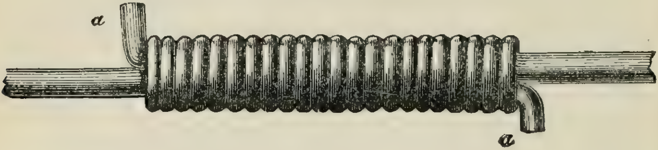
This post is formed of two tubes, one set upon the other, and the bottom of the lower one made fast to a bent plate of iron buried in the ground. One of them is shown in Fig. 356. The base consists of one of Mr. Robert Mallet's patent buckled wrought-iron plates, 1 foot 9 inches square, bent in a dish form. The buckled plate *a a* is secured by four bolts to the socket *b b*—a cast-iron cylindrical tube, 7 feet long and 4 inches outside diameter. Near the top, inside, the socket is furnished with a flange, upon which the bottom of the upper or main post, as it is called, rests. This upper post *c c* is of wrought iron with welded joints; it stands 12 feet high out of the socket, and is somewhat conical. At its upper end an iron ring is welded in to carry an iron rod *d*, 20 inches long, forming the lightning-guard. The stretching-posts are of the same height, but of larger diameter and stronger than the ordinary ones.

(251) **Iron Wire.**—The wire used generally all over the world is made of iron, which is 'galvanised' or coated with zinc. Its dimensions vary with the length of line traversed. In India No. 1 (*vide* table, p. 444) was much used, but No. 4 is now more generally employed everywhere for long circuits. No. 8 is that most generally used for average circuits, and No. 11 is used for short lines. In the open country galvanised wire appears indestructible, but in the neighbourhood of large towns the sulphurous acid vapours arising from the combustion of coal combine with the zinc and form a soluble compound. Hence rain soon washes away the formation, and the wire corrodes. Wires are now frequently protected in such places with hemp and tape well saturated with pitch, resin, and other compounds. Joints in land

line-wire are sometimes made by bringing the ends together and wrapping them with a binding wire, sometimes by twisting them round each other.

Fig. 357 represents a joint made by the former method, called the 'Britannia' ioint. The wires to be joined are bent at right

Fig. 357.



angles, about half an inch from the ends, as at *a a*. They are then laid together, and wrapped or bound with galvanised iron binding wire, and soldered.

By the other method the two ends are laid side by side for about 5 inches, and each turned four or five times round the other, with a space between the two helices of about three-quarters of an inch (Fig. 358). To make this joint, however, it is necessary

Fig. 358.

that the wire should be quite soft at the ends, a condition which must be seen to beforehand. It should, however, be borne in mind that all joints should be carefully *soldered*; otherwise the conductivity of the wire is much impaired.

(252) **Compound Telegraph Wire.**—This, although a comparatively new invention, has nevertheless been extensively used in the United States of America, Brazil, the River Plate, Central America, Russia, Japan, China; by various European telegraph administrations, and also for military field telegraph service.

The compound wire consists of a steel wire around which a copper strip is wound helically; both steel and copper, having been drawn through a draw-plate, are firmly soldered together and tinned. They thus produce a compound wire, which combines lightness with strength and high conductivity.

The advantages of the compound wire over iron wire are eminent, and show the following important results:—

The proportion of weight between ordinary iron wire and compound wire of equal conductivity is about 3 to 1—that is to

say, compound wire only weighs $\frac{1}{3}$ of iron wire of equal electrical capacity. This light weight, when compared with the weight of an ordinary iron wire of equal conductivity, offers an advantage which is of the greatest importance in constructing telegraph lines, especially in countries where the transport of materials is expensive, as a saving of 67 per cent. in cost of transport is effected.

Expense is also saved in erecting the compound wire, as the lightness of this wire economises time and labour, and requires but from two to three joints per mile. On account of its small weight the poles will carry a larger number of compound than of iron wires, and the insulators may be of lighter and less costly construction.

A line with a given number of poles will therefore be more substantial and durable with compound wires than with ordinary iron wires. The strain and weight upon the poles (especially at curves and angles) being less, the line must necessarily stand firmer, and the smaller diameter of the wire offering less surface to the pressure of storms, to the accumulation of sleet, &c., renders the compound wire less frequently subject to temporary interruptions.

Compound wire, being a steel wire protected by a thick sheath of copper and tinned, does not corrode like iron wire, therefore is less liable to breakage. Its superiority in this respect has been tested by a series of severe experiments, in which compound wires and iron wires have been exposed to the influence of air under pressure, the air being alternately impregnated with acid and salt. The results proved that an iron wire of 4 millimetres diameter was on the ninth day partly destroyed, whereas the compound wire remained in a perfect state of preservation.

Compound wire is especially well adapted for military telegraph lines, and has given ample proofs of good field service. It is further well adapted for long spans, for crossing rivers, ravines, mountains, for overland lines in towns, &c.; and it has been found that stretches from a quarter to three-quarters of a mile can be successfully maintained.

(253) **Birmingham Wire Gauge.**—The following table of sizes and weights is that usually adopted in this country :—

Table of Iron Wire.

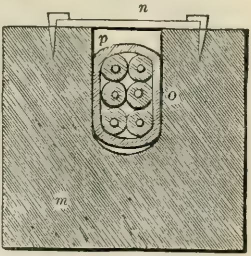
Birmingham Wire Gauge	Diameter	Area of Section	Weight of 100 Yards	Weight of 1 Mile	Breaking Strain	
					Hard Wire	Soft Wire
	Inches	Sq. Inches	lbs.	lbs.	lbs.	lbs.
00	0·363	0·103	102·00	1,794	8·600	6·000
0	0·331	0·086	84·72	1,490	7·100	4·750
1	0·300	0·071	68·75	1,210	6·000	4·000
2	0·280	0·062	59·90	1,054	4·850	3·400
3	0·260	0·053	51·65	909	4·000	2·900
4	0·240	0·045	44·00	775	3·400	2·500
5	0·220	0·038	37·00	651	2·950	2·200
6	0·200	0·031	30·56	538	2·500	1·800
7	0·185	0·0265	26·15	461	2·200	1·520
8	0·170	0·023	22·10	389	1·750	1·200
9	0·155	0·0195	18·36	323	1·500	950
10	0·140	0·016	14·97	264	1·200	820
11	0·125	0·125	11·95	211	820	650
12	0·110	0·010	9·24	163	710	510
13	0·095	0·0071	7·05	124	640	400
14	0·085	0·0057	5·51	97	510	350
15	0·075	0·0044	4·29	76	410	300
16	0·065	0·0033	3·22	57	350	200
17	0·057	0·0026	2·48	44	280	150
18	0·050	0·0020	1·91	34	200	115
19	0·045	0·0016	1·55	27	150	85
20	0·040	0·0013	1·22	21	110	65
21	0·035	0·0010	0·94	17	85	50
22	0·030	0·0007	0·69	12	65	40

(254) **Underground Wires.**—The following details of the system of underground wires, as adopted by the late Magnetic Telegraph Company, were kindly furnished by Mr. Bright:—

'It was evident that the integrity of the insulating coatings of gutta-percha could not be preserved long without some external protection throughout the length of each line, as the mere compression of the soil, gravel, and stones would at once have injured it, and in opening the roads for repair they would experience still further damage. After discussing the merits of various plans of protection, it was finally decided that the wires throughout towns should be laid in cast-iron piping divided longitudinally, so that the wires might be laid in quickly without the tedious and injurious operation of drawing them through, as was the case with the old system of street work, where the wires were laid in ordinary gas piping; and that along the country roads, which were comparatively little liable to disturbance from the construction of sewers, or laying of gas or water pipes, the wires should be laid in *creosoted* wooden troughs of about 3 inches scantling, cut in long lengths, so as to be little liable to disturbance upon any partial subsidence of the soil, which not unfrequently occurs in districts where mining operations are carried on. The tops of the troughs are generally protected by fastening to them a galvanised iron lid.'

A section of one of the troughs is shown in Fig. 359; *m* being the trough; *n* the galvanised iron lid; *o* the gutta-percha wire; and *p* a lapping of tanned yarn. The trough is deposited at a depth of two feet from the surface of the road. The iron piping used in towns is about 2½ inches in diameter. The lower halves are first laid, socket into socket, in the trench, and the wires are then rapidly reeled off, and deposited in the lower halves from a drum drawn over the trench. The upper halves are then put on, and attached to the already laid portions by clamps or bolts fastening through ears cast in the sides of the pipes.

Fig. 359.



The late Magnetic Telegraph Company adopted the underground system to a great extent. In 1851, they laid a line between Liverpool and Manchester; they afterwards extended the system from London through Birmingham to Manchester, Liverpool, and the various towns in the Lancashire districts, and northwards to Scotland.

The late Electric Telegraph Company also adopted a line of underground telegraphs: this consisted of 8 wires drawn into earthenware pipes, buried alongside the London and North-Western Railway from Kilburn to Manchester and Liverpool.

The late British Telegraph Company also went largely into underground work on the system previously explained.

There seemed, however, some fatality with regard to the underground system, for it was gradually removed, so that at the present time none of the old work remains. The failure may principally be traced to the want of knowledge of the material employed, and to a consequent carelessness in the manipulation of the insulating material. Amongst the failures that relative to the British Company is most interesting, for their engineer, Mr. E. Highton, investigated some of the peculiarities of the failure. The following extracts are taken from his reports, which are dated 1857 and 1858:—

'Having understood that the wires south of Berkhampstead had failed in many parts, I went there yesterday,[1] with a view of endeavouring to ascertain the cause of such failure. I selected for examination a district commencing about a mile to the south of Berkhampstead. I selected a length where the wires passed near the roots of oak trees, and then near the roots of ash and Italian poplars, with only one oak tree among them. I found

[1] September 1856.

the wires and wooden boxing had failed, and had been renewed for several yards in passing every single oak tree, including the isolated one above mentioned, and nowhere else.

'I had the earth removed from the wires at various places, and selected, in particular, those spots where the newly replaced wires and boxes joined the old wires and boxes. I found the boxing laid down in March last in a state of decomposition, whilst old boxing, put down some two or three years ago, and within seven yards of the same, was perfect. I have found wires perfectly good and completely rotten within seven yards of each other This proved the action to be local. My attention was then directed to the probable cause of the decay.

'On opening the first part where the wires were decayed, I observed a remarkable peculiarity in the soil; I detected, at once, a whitish-looking plant, resembling the spawn of the mushroom, or some other fungus, pervading the soil and filling every crevice; I found that it had utterly destroyed all the dead roots of the oak and the plants in the hedge. Its branches spread all over and around the wooden trough, covering it with a whiteness resembling a whitewash. I found that wherever the plant touched the gutta-percha wires the gutta-percha was rotten.

'On my first noticing this peculiar subterraneous plant, I thought it might be the spawn of a certain fungus. I immediately searched for funguses under those oak trees; I found a yellowish green fungus luxuriantly growing under every single oak without exception, but not one under an ash or other tree.

'The plant possesses a powerful odour; after breaking soil a few inches deep, its scent can at once be detected. The presence of the plant and the decay of the wires I found coincident; the absence of the plant and a *most* perfect state of the wires, coincident also.

'On Tuesday last I examined the wires between Warwick and Birmingham; my attention was first directed to a place where the wires passed under a very large oak tree, the stem being 16 feet in circumference at 3 feet from the ground, and the branches extending 45 feet from the stem. The tree is known in the neighbourhood as Old Parr's Oak. The wires under this tree have decayed and have been renewed.

'I found the wooden lid of the testing-box decayed, and covered with both dead and living mycelium of a fungus. I found on the gutta-percha of the wires in the 2 feet which I opened two portions of the mycelium of a fungus, each in area about the size of a penny-piece, and also one under the lid of the test-box.

'A few days ago I examined a spot near Canterbury where the gutta-percha of the wires had entirely decayed.

'The soil was pure, clean, sharp, red sand, and there appeared nothing in such soil to induce decomposition.

'But at that spot I found a young oak tree, which could only derive its nourishment from the ground through which the wires passed; and upon these roots, both living and dead, I found what I believe to be the mycelium of a fungus, the same as that which I discovered under the oak trees at Berkhampstead.'

Again in 1858 he wrote:—

'I beg to hand you several specimens of guttapercha-covered wire, and also sheet gutta-percha, which have been experimentally subjected to the action of the mycelium of a fungus—viz. the *agaricus campestris.*

The gutta-percha was placed in different parts of a bed of soil 5 ft. 6 in. wide by 5 ft. 3 in. long. The spawn of the fungus was placed in the soil, at intervals, over that space, in the month of September 1857.

'The mycelium traversed the whole of the bed.

'The gutta-percha sent has not been touched by the hand or a tool until exhumed on the 25th of January, 1858.

'The several specimens sent will show the complete destruction of gutta-percha by the mycelium of a fungus, and prove, I trust, the correctness of the opinion I expressed many months ago.'

Mr. George Saward, in his evidence before the Submarine Telegraph Committee in 1861, remarked, that in an examination of the London and Manchester underground wires he found the gutta-percha wires decayed, and universally the case wherever oak trees or oaken posts drained on to the line. A remarkable instance occurred in the Edgware Road, where a series of posts and rails were placed along the side of the road to protect the footpath, which is higher than the other portion of the road. The wires were laid in the lower portion, and it being a gravelly soil any drainage trickled down in the direction of these wires. More than a mile of the wire was taken up, and there was the mark of every post along the gutta-percha where it was taken up; wherever there was drainage from an oak post, there was a piece of decay.

Attention has lately again been turned to the subject of underground telegraphy. Germany has adopted an extensive underground system. Daily the question must become of greater importance, for not only are the available routes by road, rail, and canal being rapidly filled up, but each winter, with its storms of wind and snow, produces such serious interruptions that communications have frequently been impossible between the metropolis and the provinces. It can therefore be well understood that reliable communication by means of main trunk underground lines is most desirable. In 1871 the Post Office laid down a line of fourteen wires between Manchester and Liverpool, and in the following year a line also from the centre of London to Hounslow. An extensive underground system also exists in London and in all chief towns. Iron pipes are generally used in towns, buried at a depth of about one foot six inches; and stoneware pipes in country roads, buried two feet deep. The diameter of the pipes depends upon the number of wires to be carried. Leaded joints are employed with iron pipes, but clay only is used with the stoneware pipes. The guttapercha-covered wires are formed into cables, which are drawn into the pipes. The gutta-percha wire commonly used in England is of No. 7 gauge, and is composed of—

Copper wire (No. 18)	= 39 lbs. per mile
Gutta-percha	= 46 „ „

In European cities the amount of underground work is small, and is only carried out where absolutely necessary. In Switzerland the lines cross the Alps at various places at an elevation of 7,900 feet, and the plan is adopted of a cable consisting of the necessary number of guttapercha-covered wires protected with layers of hemp soaked in Chatterton's compound; the whole is enclosed in a leaden tube, and buried in the ground to a depth of from two to three feet; the cable is surrounded by sand, and covered with flat stones, the trench being filled up with ordinary gravel. In Austria the cables are of the usual insulated wire, covered with a layer of tarred hemp, and protected by a sheathing of galvanised iron wire $\frac{1}{8}$ in. diameter. In Vienna these cables are buried $6\frac{1}{2}$ feet deep in a wooden tube, the tube being filled with a mixture of tar and bituminous lime, and of these wires in Vienna not a single one has suffered any injury or decrease of its electrical properties.

In Germany cables have been laid covered with iron wire and placed in the ground without any further protection; and across the Andes in South America a cable was laid covered with Siemens' copper-strip covering.

(255) **The Earth Circuit.**—It had been shown in 1747 by Watson that a Leyden phial could be discharged through a circuit one-half of which consisted of moist earth. It appears that Steinheil was the first to employ the earth to act the part of a conducting wire in an electro-telegraphic circuit. The two extremities of the wire of his telegraph, constructed by him at Munich in 1837, were attached to two copper plates which were buried in the earth. He attributed the transmission of the current to the direct conductibility of the earth.

It was proved on a larger scale in 1841, by Cooke and Wheatstone, by experiments on the Blackwall Railway, that the earth may be successfully employed to replace one-half of the conducting wire, and to be used for the *return* circuit. In fact, they found that the earth offered so little resistance to the transmission of electricity that the same pile would work to a much greater distance with a circuit half wire and half earth than when altogether wire.

It was noticed by Bain in 1841, whilst engaged on some experiments with an electro-magnetic sounding apparatus, that, if the wires were not perfectly insulated from the water, the attractive power of the electro-magnet did not entirely cease when the circuit was broken. He found also that, when a plate of copper was buried in moist earth, and associated through the galvanometer with a similar plate of zinc also buried at a considerable distance, a current of considerable intensity passed. By increasing the size of the plates, he not only obtained powerful electro-magnetic

effects, but also electrotype deposits, when the plates were more than a mile apart, and he found that the battery thus formed continued to work for a great length of time.

Matteucci made, in 1844, numerous experiments on the conductibility of the earth for the electric current (*Comptes Rendus*, June 3, 1844). He made the current from a single Bunsen's element circulate in a copper wire 9,281 feet long, and through a bed of earth of the same length; and he found that the diminution which occurred in the intensity of the current was such that the resistance of the bed of earth must not only be regarded as nothing, but that further the resistance of the copper wire entering into the mixed circuit must be considered as less than that presented by the same wire when it enters *alone* into the circuit, thus confirming the previous observations of Cooke and Wheatstone. Matteucci regards the earth as a conducting mass of varying resistance, its great volume making up for its inferior conductibility, and he quotes the following experiment as conclusive against the hypothesis that the two electric charges liberated at the extremities of the pile always find a means of diffusing themselves into the earth, which, being a universal reservoir, succeeds in neutralising their charges with its natural fluid decomposed by the free end of the pile (*Comptes Rendus*, January 11, 1846):—

'The circuit of a pile of 10 Bunsen's elements was established by plunging the two poles in two wells 160 metres apart, a galvanometer being in the circuit to ensure the passage of the current. In this interval were two other wells, almost in a straight line with the two extreme wells. The distance between these two wells was 30 metres; they were distant from the two extreme wells, one 80 metres, the other 50. The extremities of a good long wire galvanometer were plunged into the two intermediate wells; the current was thus passed in the long circuit, when a deviation of 35° or 40° was instantly obtained. On reversing the direction of the current in the long circuit, that of the *derived* circuit was likewise inverted. This is precisely what ought to be the case if we admit that the electric current is transmitted in the ordinary manner, whilst it cannot be conceived under the other hypothesis.'

The earth is regarded by many as a reservoir or drain, in which the positive electricity on the one side and the negative on the other are absorbed and lost.

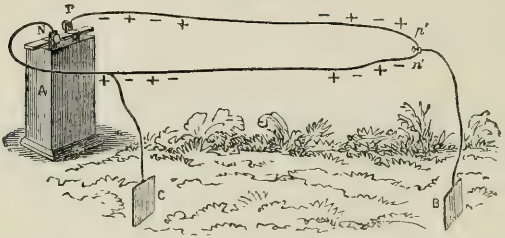
Thus let A (Fig. 360) represent the cell of a voltaic battery; P and N being its two poles united by a metallic conductor. According to the theory of Ampère, the electricity set free at the positive pole, meeting with a resistance in the conducting wire, decomposes the neutral electricity of the nearest molecule, attracting the negative and repelling the positive; the positive fluid of the first attracts the negative electricity of the second, and repels its positive; this again acts on the neutral electricity of the third, and so

on, the decomposition proceeding step by step, the positive electricity of the last molecule, *p*, being neutralised by the negative electricity emanating from the N pole of the battery.

Immediately succeeding the first series of decompositions is a second series of recompositions; the last negative molecule, *n*, being separated from its associated positive molecule, and thus becoming free, now combines with the positive molecule which precedes it, the negative molecule of which combines with the positive immediately behind it, and so on, step by step.

Suppose now the metallic circuit to be broken between two free molecules, + *p'* on the positive side, and + − *n'* on the negative, and that a communication be made with the earth through the metallic plates B and C. The

Fig. 360.



positive molecule will be brought into contact with an enormous reservoir, into which it will flow without meeting with any resistance; it will not therefore exercise any decomposing action, being in fact simply absorbed. The preceding negative molecule, being again set free, will immediately combine with the contiguous positive molecule, and the same thing happens at the negative end of the battery. A *double* series of decompositions and recompositions thus take place, and this only in one-half of the circuit; the resistance is consequently reduced one-half, that is, the intensity of the current is doubled.

The following explanation of the manner in which the earth acts when forming part of a circuit, is given by Gavarret (*Télégraphie Electrique*, p. 35):—

'The poles of a battery when disconnected have equal and contrary tensions. When insulated conductors are placed in contact with them, they themselves become the poles of the battery, which furnishes a sufficient current to charge them, but not of sufficient duration to move a galvanometer needle.

'If the conductors are enlarged, the time occupied in charging them will increase, until, as they are still further enlarged, a limit will be reached at which the flow of electricity into them will *last long enough* to affect the galvanometer; and when the conductors become infinitely long or infinitely large, the time occupied in charging them also becomes infinite, or, in other words, the current will pass precisely as if the poles were connected.

'Thus, when the extremities of a circuit are connected to the earth,

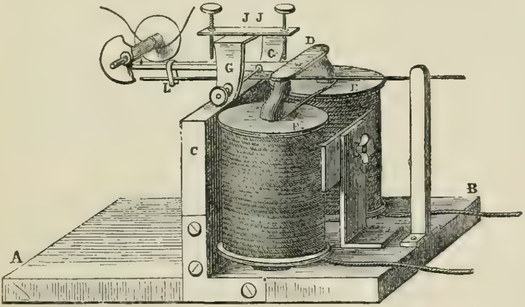
which is an infinitely large conductor, their respective tensions are diffused in all directions without producing any appreciable tension in the earth itself, so that the current will continue to flow.'

Matteucci's views are those which are generally adopted.

(256) **The Morse Printing Telegraph.**—This instrument, which, slightly modified and improved, is of all the forms of telegraphic apparatus hitherto invented the most extensively used, was conceived by Professor Morse in 1832, though it does not appear that he can lay claim to an earlier date than 1837 for its actual construction (Moigno, *Télégraphie Electrique*). The original contrivance included a pen at one end of a wire, which, as contact was made and broken, produced an arbitrary alphabet of dots and dashes representing definite characters.

On a wooden platform, A B (Fig. 361), is fixed a vertical support, C, to which is screwed an electro-magnet, E F; on the upper part of the vertical

Fig. 361.

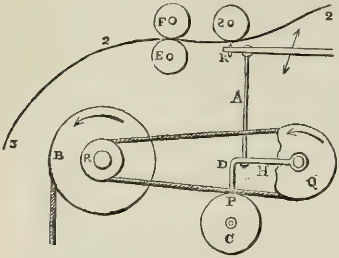


support is a metallic band, G G, the sides of which are pierced horizontally to carry two screws tipped with sharp and tempered steel points, between which the lever L moves with as little friction as possible. To one of the extremities D of the lever is soldered the armature of the electro-magnet; the other end carries one or more steel points, which fit corresponding holes in a steel cylinder, under which a sheet of paper to receive the transmitted message passes, being unwound regularly by clockwork. The galvanic current being established, the armature of the electro-magnet is attracted, and, at the same moment, the points at the opposite end of the lever come into contact with the cylinder, and make marks on the paper of greater or less length, according to the interval of time elapsing between the making and breaking of the circuit. To secure the rapidity and certainty of the contacts, a metallic plate, J J, is fixed across the band G G, carrying two screws, the extremities of which serve to regulate the motion of the lever, and to keep it within certain narrow limits, just sufficient to secure exactness and regularity. The paper is in one continuous length, and is wound

tightly round a wooden cylinder, from which it is afterwards cut into convenient lengths.

The operation of the instrument is as follows:—Motion is given to the drum or barrel B (Fig. 362) in the direction of the arrow by a weight attached to a cord acting on wheelwork within; the motion is communicated through a series of intermediate wheels to the cylinder E, between which and the cylinder F the paper passes; F is kept in close contact with E by means of a spring; S is the steel cylinder underneath which the paper passes, and R is one of the steel points attached to the lever L (Fig. 361); the pulley Q receives motion in the direction of the arrow from the pulley R in the centre of the barrel B. It carries on its axis a horizontal arm, H, which is immediately under the lever; it is bent at D so as to come into contact with the wooden friction-wheel C at the point P. This friction-wheel is fixed under the last screw of the machine, and below the lever. From the lever L proceeds a strip of metal, A, which traverses the arm H; a screw and nut, I, placed at the extremity of the rod serving to lengthen or shorten it. It must act freely at its point of junction with the lever, as well as at its point of junction with the screw H; it also works a hammer, which striking a bell below the platform of the apparatus, warns the operator when a signal is about to be transmitted.

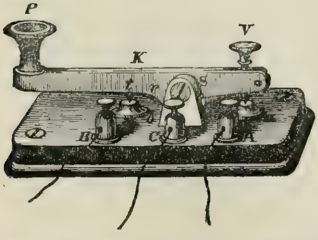
Fig. 362.



Now as long as the bent arm H D is in contact with the friction-wheel, the whole machine is at rest; but when by the action of the electro-magnet on the lever the rod A is raised, the weight, being no longer restrained, gives motion to the barrel B, and the apparatus is put in action, but is again stopped the instant the bent arm touches the friction-wheel. In this way the operator, both near and at a distance, has perfect control over the instrument.

The key or apparatus for opening or shutting the circuit is shown in Fig. 363. K is a brass lever, having at the extremity of the longer arm a button, P, of insulating material, and at the other a screw, V, which passes through the lever, and the point of which can be adjusted to any degree of projection. A steel point, *t*, is attached beneath the longer arm of the lever, and two contact pieces of brass, *a* and *b*, are fixed beneath these points. A small spring, *r*, serves to keep the lever in its normal position, V being in contact with *a*, and *t* separated from *b*. The lever is in connection with the line wire through the fulcrum S and the bind-

Fig. 363.



ing screw C; *b* is in connection with the positive pole of the battery through B; and *a* is in connection with the instrument through A. When V and *a* are in contact, a current coming from the distant station passes from V to *a* and to the earth through the instrument. When the button P is depressed, a positive current is transmitted on the line to the distant station, and a series of currents of different duration, and at various intervals, can thus be transmitted, producing corresponding signs on the receptor of the distant instrument.

The Morse code is framed on the combination of a long and a short current of the same kind, separated by intervals of three different lengths; the shortest used between each current, the next between each group representing a letter, and the longest between each series of letters representing a word. *Reverse* currents have been used to produce these intervals, and an alphabet formed of groups of positive and negative dots. A Morse code common to all usual languages is now almost universally adopted. The following is that in use in our Post Office telegraphs:—

THE ALPHABET.

A - —	J - — — —	S - - -
B — - - -	K — - —	T —
C — - — -	L - — - -	U - - —
D — - -	M — —	V - - - —
E -	N — -	W - — —
F - - — -	O — — —	X — - - —
G — — -	P - — — -	Y — - — —
H - - - -	Q — — - —	Z — — - -
I - -	R - — -	

NUMERALS.

1 - — — — —	5 - - - - -	9 — — — — -
2 - - — — —	6 — - - - -	0 — — — — —
3 - - - — —	7 — — - - -	
4 - - - - —	8 — — — - -	

Bar of Division, for fractions (as in $\frac{3}{8}$), — — — — — —
Do. for shillings (as in 2/3), . . .

PUNCTUATION, &c.

Comma (,) - — - — - —	Parenthesis ( ) — - — — - —
Full stop (.) - - - - - -	Inverted commas (“ ”) - — - - — -
Break Signal (between the address ‘To’ and the text) - - - - -	Understand - - - — -
Interrogation (?) - - — — - -	Rub out - - - - - - - - - -
Hyphen (-) — - - - - —	Go on — — -
Apostrophe (’) - — — — — -	Wait — — — — - —
Fresh Line — — - — — - —	Right - — - —
Underlined - — - - - — - -	Cleared out — - — -

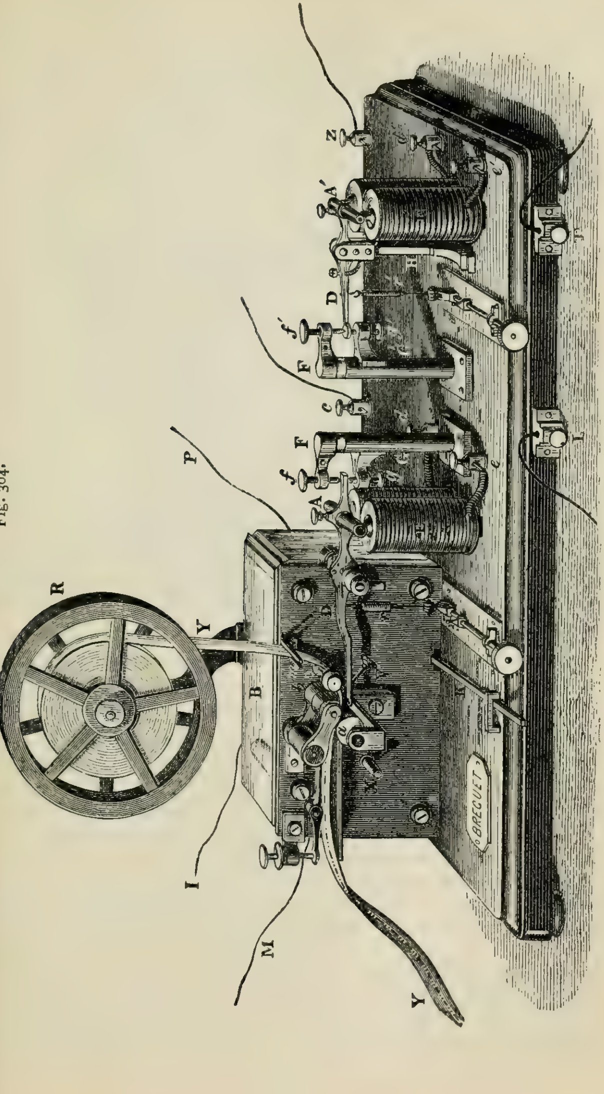
(257) **Relays.**—These are instruments designed to re-transmit signals into a fresh circuit from a local battery. In the original form of the Morse instruments, considerable force was required to emboss the signals on the paper, and the currents received at the station from long distances were found not of sufficient power to produce the required effect. Relays are of various forms; for rough work, an instrument of the simplest construction is used in France (Fig. 364). A soft iron hollow cylindrical armature on one end of a rocking lever is attracted downwards by the two poles of an upright horseshoe electro-magnet during the passage of a current. An antagonistic spiral spring lifts the armature again when the current ceases. This spring can be adjusted by a screw. The contacts required are on the rocking lever. A good relay should possess the following properties (*Jury Report on Electrical Instruments, International Exhibition*, 1862):—It should be easily adjusted, so as to work with any required strength of positive or negative current. It should work freely under the influence of an extremely small rise and fall of current above and below the strength of current to which it is set, and when once adjusted to a given strength, it should be constant—that is to say, should always work with the same rise and fall above and below the strength to which it is set. The moving parts should be very light, and traverse the shortest possible space, in order to allow rapid work under the influence of small forces. Finally, the contacts should be so arranged as to be easily adjusted and cleaned.

The condition of constancy in a relay is extremely difficult to fulfil where electro-magnets are used, in consequence of the residual magnetism of the soft iron cores. A negative signal occurring after a series of positive currents, or after a long positive current, does not produce the same effect on the soft iron as a negative signal occurring after a series of negative currents, or after a long negative current, and neither effect will be the same as that produced by the first few currents received after the soft iron has been for some time free from all electric influence. This difficulty has led to the adoption of polarised relays.

A view of a complete Morse instrument, with the relay which has been extensively used throughout Europe, is given in Fig. 364.

E is an electro-magnet wound with a great length of fine wire, having a resistance ordinarily of about 120 miles; a metallic support H carries a lever D, to one end of which is attached a soft iron armature A′ in the form of a split tube, with the view of getting rid of residual magnetism as far as possible from the part which approaches the electro-magnet; the other end of the lever works between the points of the two screws f' and g'; g' is insu-

Fig. 364.



lated and supported by the hollow pillar G′; *f* is connected with a rod of metal inside this pillar, and insulated from it. A spiral spring *r′* is adjusted so as to draw D away from *f* when in a state of repose, and *f′* is so adjusted that when the armature A′ is attracted by the electro-magnet, they cannot *touch* one another, being prevented by the contact between *f′* and D′; D′ is in connection with the zinc of the local battery through H and Z; *f* is in connection through F′, and *e* with one end of the coil of the electro-magnet E, which works the apparatus. The copper pole of the local battery is in connection with the other end of the coil of E through *c* and *d*.

The current from the distant station arrives at L, passes to *e*, and through the coils of the relay magnet to *d*, and so to the earth through T; E′ becomes magnetic, attracts A′ and makes contact between D′ and *f′*, thus completing the circuit of the local battery through the electro-magnet E. The electro-magnet E has an armature A which is attached to a lever D, adjusted in the same manner as D′, by two screws *f* and *g*, insulated from one another, and a spiral spring *r*; the other extremity of D carries a screw point V placed opposite to a groove in the barrel *b*, and adjusted so as to be in contact with it when E attracts A. A ribbon of paper, about half an inch wide, is coiled on the drum R, passed through the guide *m*, under the spindle O, and between the two rollers *b* and *a*, which grip the paper between them and draw it through at an uniform rate as *a* rotates by the action of clockwork inside the metal case B. The clockwork is set in motion or stopped by moving the lever *k* to the right or left.

To receive a message, the clockwork is set in motion, and as each pulsation of electricity which arrives from the distant station communicates magnetism to E, through the means of the relay and local battery, it attracts A with considerable force, and presses the point of V into contact with the paper ribbon as it is drawn through the rollers, and according as the duration of the current of electricity is longer or shorter, a longer or shorter mark is embossed on the paper. The moment the current ceases, the spring *r* draws the point away again from the paper.

Instead of embossing the signals on the ribbon of paper by mechanical pressure, the paper may be saturated with a solution of ferrocyanide of potassium, and caused to pass over a brass wheel in connection with the positive pole of the local battery, the negative pole being connected with an iron point which is kept in contact with the paper by a spring. A chemical decomposition is thus produced by every current which passes, *Prussian blue* being the result, in which colour the signals are printed. This method was invented by Mr. Bain in 1843.[1]

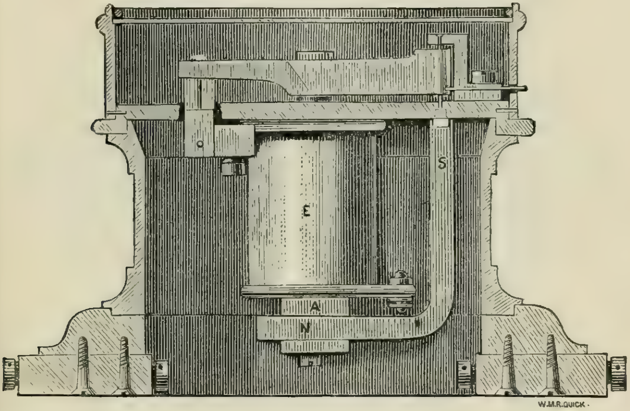
(258) **Siemens' Polarised Relay.**—In this relay the armature and the soft-iron cores of the electro-magnet are oppositely polarised by contact with a permanent magnet. Fig. 365 is a

[1] This process has again been revived, and many of the long circuits in the United Kingdom worked by the Wheatstone automatic have a Bain receiver. Its use is found to increase the speed, as it is more sensitive than the mechanical receiver ordinarily used.

sectional view in the direction of the armature, and Fig. 366 a top view.

The perpendicular electro-magnet, E, is composed of two cores of soft iron united below, in the ordinary manner, by a cross-bar, A, also of soft iron. The coils of wire terminate at the screws 1 and 2. The north end, N, of an angular-bent permanent magnet, N S, is screwed on to the cross-bar, A, to which it communicates north polarity beyond the point of contact, and also to both the cores and poles of the electro-magnet, E. The soft iron tongue, C, is supported on an axis in a slit in the south end, S, of the per-

Fig. 365.

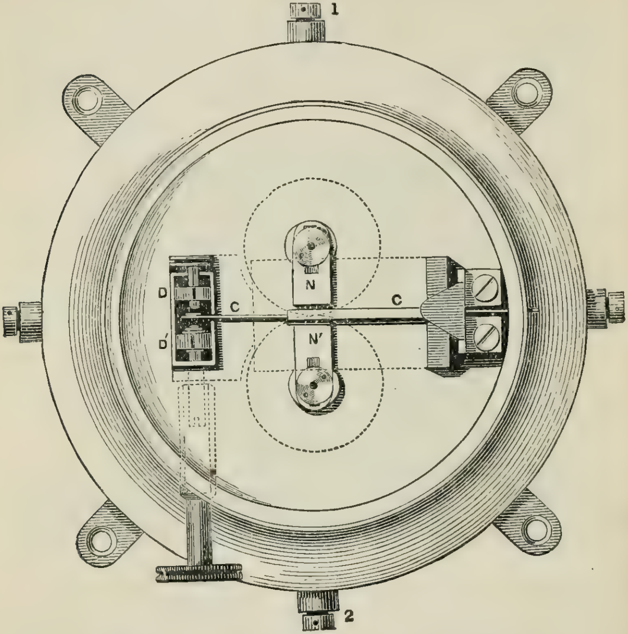


manent magnet, and thus receives south polarity. This tongue is so placed that it may oscillate between the poles, N and N′, of the electro-magnet. Its play is limited by the contacts D and D′. D is used as a contact for closing the local circuit, in which are included the printing instrument and the local battery, when the tongue, C, strikes against it. D′ is furnished with an agate point, and while the tongue rests gainst it the local circuit is open. A and B are the terminal screws of this circuit.

Whilst it is situated equidistant from both the north polarised ends, N and N′, of the electro-magnet, the south polarised tongue, C, is attracted towards each of them with equal force. When, at the sending station, the key is pressed down, the current passes through the line and relay, which has the effect of magnetising the pole N of the electro-magnet north and the pole N′ south ; but as both poles were previously north by the influence of the permanent magnet, N S, the effect of the current is to strengthen the north magnetism of N, and at the same time to weaken only that of N′. The tongue, C, is, therefore, attracted to the pole N with double force, and remains on that side after the cessation of the current, attracted by the pole N, whose distance from C is then less than that of N′. The platinum contact of C remains against D, and closes the local circuit until the key at the trans-

mitting station is let go back upon the reposing contact, by which a current in the opposite direction is transmitted through the relay, having the reverse effect of the last current, strengthening the north magnetism of N′,

Fig. 366.



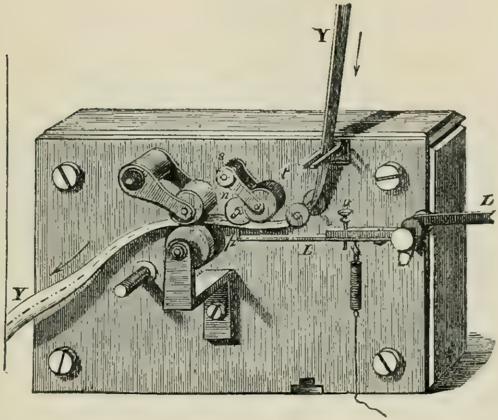
and correspondingly weakening that of N. The pole N′ thereupon attracts C against the insulating point D′, where it rests until another positive current passes and throws it off again.

When only a single battery is used in transmitting, the contact-slab which carries D and D′ is shifted, by means of the adjusting screw, so as to bring the tongue, C, when in contact with D, nearer to N′ than to N. By this arrangement, when no current passes, the contact of C is always at rest against the agate point D′ because of the superior attraction of N, and only leaves it when a current arrives, which strengthens the magnetism of N and weakens or reverses that of N′. Thus the counteracting spring used in the common form of relay is dispensed with, being replaced by the unequal attraction of the poles.

Various other forms of relay are in use, but most of them are based on the same principle as Siemens'.

(259) **Modification of the Morse Instrument by Siemens and Halske.**—The signals, instead of being embossed on the paper by pressure, are printed in ordinary printer's ink, originally suggested

Fig. 367.



by John in 1854. The mechanism by which this is effected is shown in Fig. 367, which represents the recording part of the instrument, the remainder being identical with Fig. 364.

n is a small wheel which revolves on its axis at an uniform rate by the action of the same clockwork which unwinds the ribbon of paper; *t* is an ink roller, by which the edge of *n* is kept constantly supplied with ink. L is the pen lever, which is made very light, and carries at its extremity a small projection *p*, on which the paper is supported as it is wound off the reel. The height of *p* is so regulated by the adjusting screw *o*, that the paper passes just below *n* without touching it.

When a current of electricity circulates through the electro-magnet, it attracts the armature, moves the lever L, and raises the ribbon of paper which rests on *p* until it touches the edge of *n*, when either a *dot* or a *dash* is printed, according to the duration of the current.

The amount of work to be done by the electro-magnet in this arrangement is very small; it has only to lift an inch or two in length of the ribbon of paper through the distance of about one-twentieth of an inch; consequently the current arriving by the line wire from a distant station has sufficient force to work the apparatus, and the relay and local battery can be dispensed with.

Several improvements on the original method of supplying the printing ink have been devised. Thus, instead of a moistened

felt roller, Siemens, Halske, and Co. cause a disc to be half immersed in a trough of ink, which is kept at a constant level by tilting more or less a large receiver. The disc, as it revolves in the inkstand, is always equally wet, and the refilling of the reservoir need not cause either dirt or delay. It revolves in a direction reverse to that of the paper.

(260) Very early attempts were made to print messages in roman type, and several very ingenious instruments were devised by Wheatstone, House, Dujardin, Theiler, and others, but the only one that has met with practical success is Professor Hughes's.

(261) **Hughes's Type-printing Telegraph.**—In this instrument each letter of a message is recorded by a single current only. To accomplish this, several requisites are necessary:—1. Synchronous motion; 2. An electro-magnet by which the timing of the electrical wave may be accurately measured; 3. A writing apparatus, by which the message may be correctly, rapidly, and easily transmitted; 4. A printing apparatus, by which the operator can record the message unerringly upon his own instrument, as well as upon the one at the distant station. The instrument is governed by a vibrating spring. It is a well-known law that a certain number of vibrations produces a certain musical tone; therefore, if two or more springs have the same tone, they must necessarily have the same number of vibrations in the same time. The instruments are kept in motion by a weight acting upon a train of wheels, the spring governor acting upon them by means of an ordinary escapement. These vibrations may succeed each other with any degree of rapidity required. They are regulated by a small weight attached to a spring, and raised or lowered until the number of vibrations or the desired tone is produced.

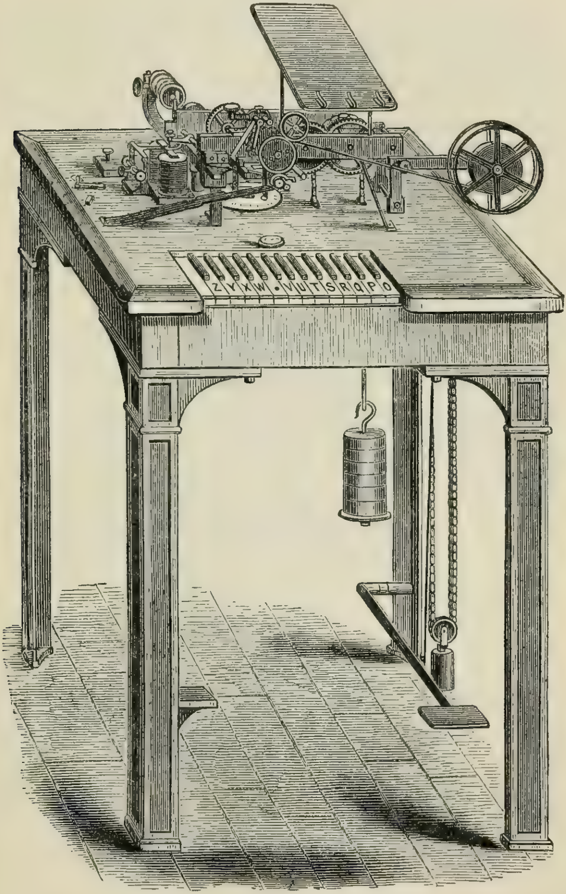
The working parts of this instrument, which is one of the most perfect printing telegraphs that have been invented, are shown in Figs. 368, 369,[1] where A is the keyboard; B the vibrating spring; C the electro-magnet; D the detent; E the type wheel; F the ink roller; G the paper printed upon; H the revolving shaft; I the revolving arm or circuit closer.

(*a*) *The Magnet.*—This is of peculiar construction. A permanent magnet polarises the cores of an electro-magnet, and holds the armature in contact with its poles. A spring is attached to this armature, and so adjusted as to exert a counteracting power a little weaker than the force of magnetic attraction. If, therefore, the magnetic force be diminished, the armature is removed from the poles of the magnet by the force of the spring. The ar-

[1] *Journal of the Society of Arts*, April 15, 1859, paper by Mr. Hyde, from which also the above description of this telegraph has been extracted.

rangement is such that the current of electricity passing through the coil when the circuit is completed, induces an opposite magnetism to that of the permanent magnet. The electrical force, therefore, which works this instru-

Fig. 368.



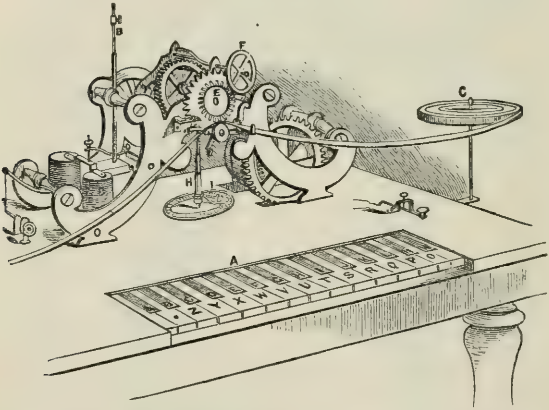
ment need not be sufficient to induce such a degree of magnetism as to render the core sufficiently magnetic to attract an armature to its poles—the practice in all other recording telegraphs. For instance, if the cores of

the electro-magnet, polarised by the permanent magnet, have a holding force on the armature of *ten*, and the spring attached to the armature be adjusted with an opposing force of *nine*, then a current of *one* reducing the force of the electro-magnet would cause the spring to rise with a force of *nine*.

This arrangement can in practice be so nicely adjusted, as to work with a very feeble current, and accurately measure the timing of the electrical wave. The armature being mechanically restored to contact with the poles, has the advantage of being acted upon by the maximum power of the electro-magnet, instead of a power lessened by more than the square of the distance the armature has to be attracted, as is the case with the relay magnets used in connection with the Morse and other systems.

(*b*) *The Transmitting Apparatus.*—The letters of the alphabet, as well as a dot and a blank, are marked on twenty-eight keys, arranged like those of a piano, save that they are alternately black and white. These keys cor-

Fig. 369.



respond to twenty-eight holes arranged in a circle on the horizontal floor or table of the instrument, immediately in front of the keys. Each key is connected by a lever with a little steel knob, which, when the key is pressed down by the finger, rises up through one of the holes. If a key marked with a particular letter be touched, the knob corresponding with this letter rises, the revolving arm passes over it, and for the instant closes the circuit, and allows an electrical impulse to be transmitted. This impulse, by arrangements presently to be described, causes the particular letter to be recorded on a slip of paper in printer's ink. The instant the arm passes over the little raised knob the circuit is broken, and if the finger were held the hundredth part of a minute on the key, the hand would pass again over the knob and the letter would be repeated. To prevent this, the hand carries after the portion of it which rides over the knob and completes the metallic contact which closes the electrical circuit, a little inclined plane, which

throws the knob out of its position, so that the hand cannot pass over it on any future revolution after the first contact. This arrangement is rendered necessary to prevent the repetition of letters, on account of the extreme rapidity of the revolving arm and recording apparatus.

(*c*) *The Printing Apparatus.*—A shaft which revolves seven times faster than the type wheel, has a flywheel upon it to overcome the inertia of a small shaft which moves the printing press. This shaft is locked to the flywheel shaft by means of a clutch which rests on a small inclined plane. Whenever this clutch is kept upon the inclined plane, by means of a detent, the flywheel shaft revolves independently of the small printing shaft; but as soon as the detent is moved by the action of the armature of the electro-magnet, the clutch locks both shafts together, and the small shaft is made to revolve one revolution, when the clutch again rests upon the inclined plane, which lifts it off the flywheel shaft. A cam is attached to one end of this shaft which lifts the press and the paper upon which the message is to be printed against the type wheel. The time of the locking of the shafts depends upon the arrival of the electrical wave, and thus, with two instruments in perfect harmony, the operator has the printing apparatus of the distant instrument as completely under his direction as the one before him. But to correct any minute variation in time between the instruments in circuit, there is a corrector or wheel attached to this shaft with hook-shaped teeth, which mesh into corresponding cavities in the type wheel. The latter being loose upon the shaft, or only held by friction, is removed backwards or forwards by the corrector to exactly the same position as the type wheel on the instrument from which the message is being sent. This correction takes place in the act of printing every letter. There is also upon this shaft a cam so arranged that the moment the armature falls off the electro-magnet and opens the detent, it forces the detent up and restores the armature to its original position upon the poles of the magnet.

The electrical circuits are exceedingly simple. The earth wire connects with the steel pins or knobs on the keys of the transmitting apparatus, and from the revolving arm through the electro-magnet, and thence through the line and distant magnet to the earth. Reversed currents are not necessary except on long submarine wires.

The mode of operating is extremely simple and easily acquired. The office desiring to transmit a message, calls the station by touching the keys in a prearranged order; the distant office at once returns the signal 'O.K.,' or all right. The manipulator then commences the message, first striking the zero key to start the distant type wheel in unison with his own. If the message is received correctly, he is allowed to finish, and then the operator at the distant office gives the signal of 'all right;' if there is a mistake, the receiving office touches his key board, which throws extra letters to the transmitting station, and he then commences again from the point where he made a mistake. There can be no mistake, however, if the operator touches the right key, and manipulators become so expert that they seldom touch the wrong one; if they do, the error is shown by the copy of the message on their own instrument, and immediately corrected.

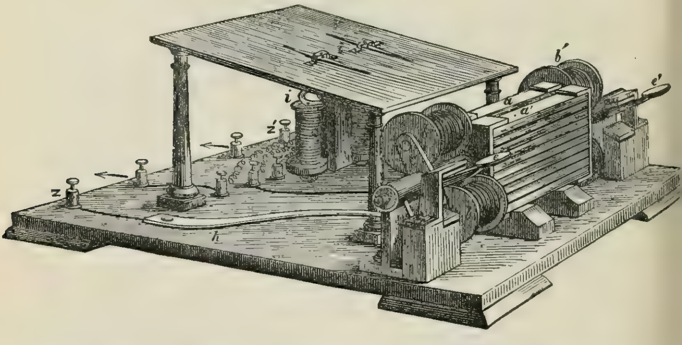
Considerable modifications have been made in this instrument in France and elsewhere on the Continent, and it is now very generally used throughout Europe. It has, however, been replaced in England by more rapid apparatus.

(262) **Magnetic Telegraphs.**—In these instruments the motions of the needles are actuated by the momentary currents induced in electro-magnetic coils when moved in proximity to the poles of a permanent steel magnet.

1. *Henley's Original Double-Needle Apparatus.*—This is shown in Fig. 370.

Two compound bar-magnets *a a* are fixed parallel to each other, so that their opposite poles are in juxtaposition. At each end of the magnets are arranged a pair of electro-magnetic coils *b b′*, which are connected together at the back by a soft iron armature *c*; each pair is attached to a separate axle and finger-key *e e′*, and are perfectly independent of each other, so that by their motion they can communicate magneto-electric currents to the two line wires *z z*. In order to avoid the friction that would ensue on the motion of the coils, if their soft iron centres were in actual contact with the poles of the permanent magnets, the axles upon which the coils are fixed are so adjusted as to bring the ends of the soft iron cores to within about one-sixteenth part of an inch from the magnets. When the sending part of the apparatus is at rest, a spring *h* keeps the coils so disposed that the centre of

Fig. 370.



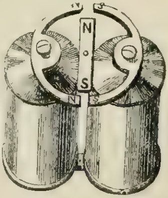
one is before one pole of the magnet, and the other before the other pole. This answers a double purpose; the iron cores and armatures of the coils act as a keeper to the magnets when the apparatus is not in use, and the position at the same time is such that the maximum of inductive effect is obtained upon the motion of the coils. The finger-key attached to the axle, on being depressed, reverses the position of the coils in relation to the poles of the magnets; the alteration in the polarity of the soft iron cores which thereupon ensues, occasions by induction a revulsion in the electric condition of the convolutions of wire forming the coils, and the current induced flows from one terminal wire of the pair of coils, through the indicating portion of the apparatus *i* in one direction to the earth, and from the other terminal wire in the opposite direction through the line wire. On the return of the finger-key to its original position, the polarity of the cores is again reversed,

and currents are induced in the opposite direction to those previously generated. The operation of the one current is to deflect, and of the other to bring back, to zero, the indicating needle of the apparatus, and of the instruments at the various stations to which the currents may pass. The motion of the other finger-key leads to similar effects being produced in connection with the other line wire; and the combinations of movements of the two indicating needles constitute the alphabet.

The indicating portion of this telegraph consists of a pair of small electro-magnetic coils coupled together by an armature; the soft iron cores project beyond the coils, and are terminated by semicircular horns of soft iron. This elongation of the cores was found necessary in order to prolong the polarisation of the coil, as the great intensity of the induced current would not occasion during its passage through the coil a sufficient amount of polarity in the iron to move the magnet of the indicating needle unless its effects were, so to speak, thus temporarily fixed. On the return of the finger-key to its original position, an amount of residual magnetism is left in the horns of the indicating coils sufficient to hold the needle in its position at zero when the instrument is at rest. By this arrangement what is technically termed a *dead beat* of the needle is produced, and the needle at the same time is in perfect equilibrium upon its axle, conditions which conduce greatly to the rapidity and invariability of the needle's motion, and to accurate interpretation of the signals. The magnets used to generate the induced currents are tempered in a particular manner, and retain their polarity for years. They are easily re-magnetised when required, by bringing their poles for a short time into contact with a powerful electro-magnet.

The form of the armature of the electro-magnet in the receiver of these instruments is shown in Fig. 371. The needle is attracted by two of the extremities of the horns, and repelled by the other two. When the current in the electro-magnet is reversed, the attractions and repulsions take place in opposite directions.

Fig. 371.



In order to reduce the resistance in the circuit, the coils of the large electro-magnet are excluded when the instrument is in the position for receiving, by the contact between the stud *h* and the spring *f*: *f* is in connection with the earth, and *h* through the press frame-work of the instrument with the coil of the electro-magnet of the receiver.

This instrument is now out of use.

2. *Bright's Magnetic Telegraph.*—This instrument was devised with a view of obviating the effects of the *recoil* currents which

always occur in the working of underground wires, interfering materially with the working of telegraphic apparatus. The nature of the interference will be at once understood when it is mentioned that with a letter-printing telegraph the surplus current has a tendency to carry the machinery on further, and to make other letters than those intended. With the chemical and other recording telegraphs, the surplus flow of electricity will continue nearly a minute, entirely confounding the marks, and running one letter into the next; and with the needle telegraphs a beat more than intended is made by the back current with every letter formed.

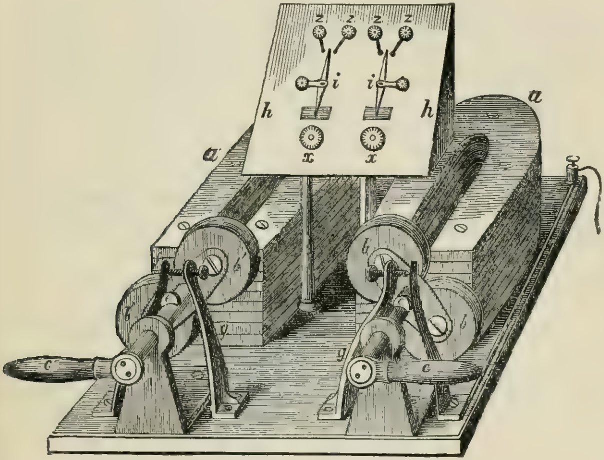
The plan adopted by Messrs. Bright was to disconnect the indicating apparatus altogether from the action of the sending currents, and only to bring it into connection with the line wires at their termination. Instead of shutting off the recoil current, it was permitted to pass through the receiving coils at the close of the sending currents, and the connections of the apparatus were so arranged that it conduced to its efficient working by keeping the needles at zero, so as to be in the proper position for receiving signals from the opposite ends of the line. A compensating apparatus was also introduced, having for its object: 1. The obviating the effects of the earth currents which continually pass through telegraph wires more or less, and in different directions, and which arise from variations of terrestrial magnetism, especially during auroræ boreales and other atmospheric electrical disturbances (60); and 2. The neutralising any excess of residual magnetism that might be engendered in the horns of the coils by the recoil current. This excess varies with the length of the circuit worked, and requires a *constant* compensation to be maintained. The apparatus consists of a permanent magnet of much greater strength than the magnet within the horns of the indicating coils, fixed upon an axis at such a distance from the lower pole of the indicating needle, that the poles of the compensating magnet may be made to describe a circle intersecting the lower pole of the indicating magnet, but being in a plane slightly removed from it, so as not to actually come into contact. By an external regulator the compensating magnet can be adjusted so that the influence of either of its poles can be brought to exercise a definite influence of attraction or repulsion upon the receiving magnet, and upon the soft iron horns of the coils by which it is moved, and thus to negative an excess of polarity in either direction. When this contrivance was adopted, not the least inconvenience was experienced from the greatest electro-terrestrial disturbances, even when they were strong enough to deflect a galvanometer needle at right angles;

nor did the strongest return current from the most extended circuit impede in the least the efficient transmission of signals.

The magnetic telegraph as thus improved is shown in Fig. 372.

a a compound horseshoe magnets, formed of steel plates screwed together; *b b* induction coils attached to axles moved by the handles *c c*; one of the wires terminating each pair of induction coils is connected with an insulated metallic *cam*; the other end of each pair of coils is conducted directly to the earth; *e e* the metallic *cams* which are insulated from the axles to which they are attached by ivory plates; *f f* two springs connected with the line

Fig. 372.



wire, and resting against the screws of the bearings *g g*; *g g* two bearings or bridge pieces in connection with the indicating portion of the instrument; *h h* the outside of the dial; *i i* the indicating needles moved by the magnetic needles inside the same axles; *x x* thumb-screws, by which the magnet regulators are adjusted; *z z z z* adjusting pins between which the needles beat.

The internal arrangement of the indicating apparatus is not shown in the figure. When at rest the spring *f* is in contact with the bridge piece *g*, and the line wire is in direct communication with the indicating part of the instrument, and the electric currents from other stations pass from the line wire through the indicating coils, and thence to the earth, producing in their passage the required signals. When, however, the handle is depressed, the metallic cam or stud attached to the axle presses the spring away

from the bearing g, and the current of magneto-electricity produced in the induction coils by their change in position as regards the pole of the permanent magnet passes direct to the line wire. This current deflects the needles of other stations from zero. Directly the downward motion of the handle is arrested, and during its return to its original position, a current in the opposite direction is induced, which flows through the line wire, bringing the indicating needle of the other stations back to zero, but not affecting its own indicating apparatus, owing to the connection between the spring and the bearing being still incomplete. The moment the spring is again in contact with the bridge piece, on the cam setting it at liberty, the line wire, in which a portion of the last current has been held as it were *in transitu*, seeks to regain its equilibrium, and the return current passes through the indicating portion of the instrument (now in circuit again), and holds the needles to zero, in the proper position to be actuated by currents from the other stations.[1]

(263) **The Acoustic Telegraph.**—Under the ordinary system of telegraphing it was necessary to employ a transcriber to write down the words as interpreted from the visual signals, and dictated

Fig. 373.

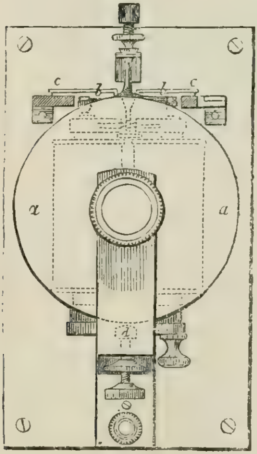
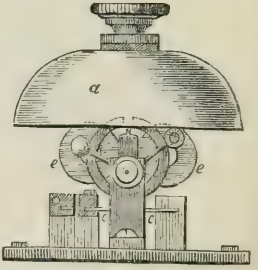


Fig. 374.



to him by the receiving operator, whose eyes, being fixed on the rapidly moving needles, could not be engaged in conjunction with his hands in writing, but now the operation may be carried on by the same person. Steinheil (229) invented an instrument which appealed to the sense of hearing, and

[1] The magnetic needle telegraphs have now been abandoned for many years.

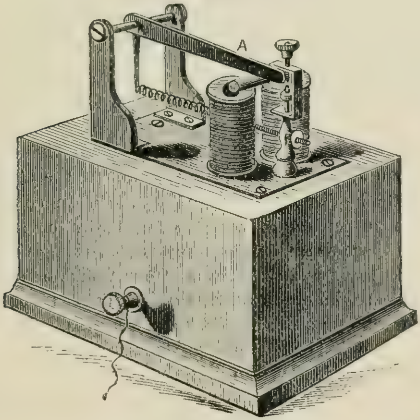
a similar plan, by which the manifestations of the current are transferred from the eye to the ear, was invented by Messrs. Bright. The apparatus is shown in Figs. 373 and 374.

a the bell; *b* the hammer; *b′* the muffler to deaden the sound and stop the vibration after each stroke; *c* the contact maker and breaker, by which the local battery is put on and shut off; *e e* (Fig. 374) the electromagnetic coils through which the local current is passed, which actuate the magnet *i*, from the axle of which extend arms bearing the hammer and muffler *b b′*; *d* a fixed muffler.

There are usually a pair of these bells together, one bell differing half an octave in tone from the other, fixed to a wooden partition, one on the one side, and the other on the other side of the operator. From the number of beats and the difference in tone the letters and words are formed in the same manner as with the needle telegraph. Acoustic instruments are quicker than visual ones; they are simpler in construction, and they are certainly more accurate in operation. Sound-reading is coming into very general use. It is almost universal in America.

(264) **The Sounder.**—This instrument is of the Morse type, but the signals are read off by sound instead of by sight from the recording slip. It is usually worked by single currents from an

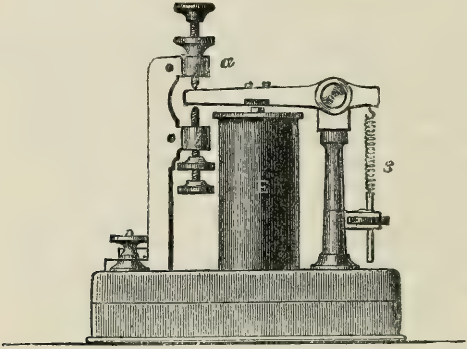
Fig. 375.



ordinary Morse battery, and its construction is that of a Morse receiver without the clockwork mechanism. Fig. 375 represents one form of sounder. It consists of an electro-magnetic coil with

an armature A fixed upon the top of a hollow case minus one end. The armature A is attached to a long lever pivoted at one end, and retained in position by a spring; the free end rests against a stud, which can be adjusted by a screw; when attracted, the lever strikes against a lower stud, which can also be adjusted. At each attraction and release a sound, loud enough to be heard at some distance, is emitted in the contact of the lever with either of the two studs. The alphabet is similar to the Morse, consisting of short and long

Fig. 376.



strokes. Fig. 376 represents the form of the sounder usually adopted in England, and is the simplest form of receiving instrument in use. E is an electro-magnet; S is the antagonistic spring to keep the armature lever against the upper stop; *a* and *b* are the adjustable stops.

(265) **Dial or Step-by-Step Telegraphs.**—These instruments directly communicate to the eye the letters of the alphabet, each of which, instead of being produced by a certain constant group or succession of currents, requires as many currents for its production as there are letters on the dial following that by which it was preceded. They are valuable from their not requiring any special training in the operator, a very little practice enabling anyone to send or receive a despatch by their means. Several excellent instruments of this class, worked by magneto-electric currents, and mostly modifications of the first form invented by Wheatstone in 1840, were shown at the International Exhibition of 1862, and have since come into very general use.

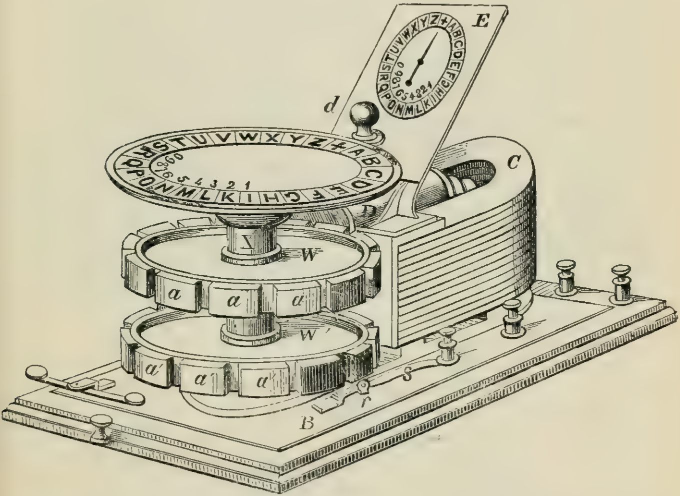
Henley's dial telegraph is shown in Fig. 377.

The horizontal dial carrying the letters is supported above the base-board of the instrument by a vertical rod, which passes through the hollow axis X

of the brass wheels W W′. The handle *d* is also attached to X by an arm underneath the dial, so that as the handle is moved round the dial, the wheels move with it: C is a compound horseshoe magnet; its power (depending chiefly on the number of laminæ or plates) is suited to the electrical resistance of the particular circuit through which it is intended to work: D is an electro-magnet, the core being in the form of a horseshoe, and the poles being vertically above one another, and between the two poles of the permanent magnet.

On the circumference of each of the wheels W W′ are secured thirteen pieces of soft iron, *a a a*—*a′ a′ a′*, of such a size, and so placed with respect to one another, that at the moment when *a* is opposite to the north pole of the permanent magnet, *a′* is opposite to the south pole; *a* imparting by in-

Fig. 377.



duction north polarity to the upper end of the electro-magnet, while *a′* imparts south polarity to the lower end. A reverse action takes place when the handle has been moved through the twenty-sixth part of the circumference of the circle (corresponding with the distance between the two letters). At the instant of each reversal of the pole of the electro-magnet effected in this manner, currents of electricity in alternate directions pass through its coils.

One extremity of the coil-wire is connected with the earth, the other with the coils of a small electro-magnet (behind the receiving dial of the instrument), through which each induced current passes, then traverses the line-wire to the distant instrument, circulates through the coils of the electro-magnet of its receiver, and so passes to the earth through a short circuit formed by the spring *s* and a screw on the metal plate B. These touch each

other only when the handle is brought to zero, a roller, *r*, on the spring passing at that moment into a notch on the under side of the lower wheel, and thus allowing *s* to rise and come into contact with B. The object of this is to cut out of the circuit the resistance of the coils on the large electro-magnet, which is equal to several miles of the line-wire.

The alternating currents of electricity, thus circulated through the coils of the electro-magnet of the receiver, work an escapement in the following manner:—

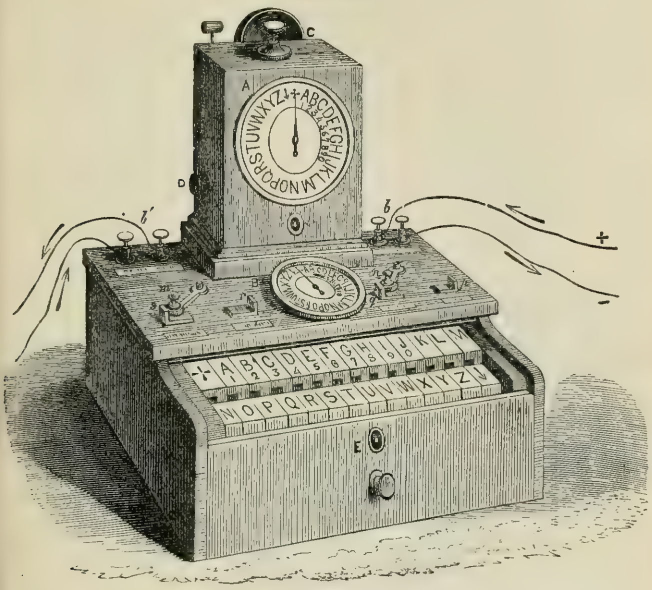
Pieces of soft iron are fixed on the poles of the electro-magnet, forked at their ends, and approaching each other very closely. The lower end of a magnetic needle hangs in the slot so formed; and being always within and surrounded by the soft iron, it is acted upon much more powerfully by the magnetic force than if it simply vibrated between the poles of the electro-magnet. The other end of the needle is formed into two pallets, which by its alternate movement act on inclined teeth on the opposite sides of an escapement wheel, the teeth being cut in a peculiar way to prevent recoil. The small index-hand of the receiver is thus made to revolve in the same manner as the seconds-hand of a watch. It is thus seen that the movements of the handle *d* will be exactly followed by the small index-hand on the receiving dials of both instruments, whatever letter is indicated by the position of *d* being also pointed out by the index-hand of the receivers; and thus messages can be sent and received by any person after a little practice, without the knowledge of a special alphabet.

The spring and button on the left of the instrument are for setting the index-hand of the receiver, should it at any time get wrong. On slightly raising the spring, the circuit is broken with the coils, so that D can be moved to the same letter on the large dial that the index points to on the dial of the receiver without any current passing. On pressing the button down, a short circuit is formed between the two outer terminals connected with the line and earth wires, so that the handle D on the large dial and the index of the receiving dial will be moved simultaneously round to zero, without affecting the distant instrument.

(266) **Froment's French Alphabetic Telegraph.**—This elegant apparatus is shown in Fig. 378. There are twenty-eight keys—twenty-six representing letters, one a cross, and the other an arrow. By pressing down any key, its corresponding letter is shown on the dial, and at the same time on the dial of a similar apparatus at the distant station. Supposing, for example, the apparatus figured in the text to be at Paris, the current from the battery enters the apparatus at *b* and leaves it at *b*′; it proceeds thence to

the distant station (say Rouen), where it traverses and works a precisely similar apparatus.

Fig. 378.



The mechanism of the internal part of the apparatus is shown in Figs. 379, 380, and 381.

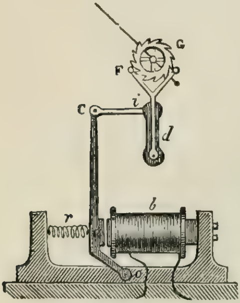
Fig. 379.

Fig. 380.

Fig. 379 is the *manipulator*, or the instrument for sending signals ; Fig.

380 is the *receiver.* The current from the battery enters through A (Fig. 379), passes up the brass spring N, which is in contact with the wheel R, and from this through the second notched spring M, out by the wire B, and on along the line-wire to the telegraph at the distant station ; there the current traverses the bobbin of an electro-magnet not seen in Fig. 379, but exhibited separately in Fig. 381. This electro-magnet is fixed horizontally at one extremity, the other being left free to operate on the soft iron armature *a*, which forms part of a bent lever, movable round the pin *o*. The lever is restored to a vertical position, when the electro-magnet is no longer active, by the action of the spring *r*. The moment the electrical current traverses the bobbin, the lever at *c* is attracted, and the motion is imparted to a second lever *d*, through the shank *i*. This second lever is fixed on a horizontal axis, and is united to the fork F. When the current is interrupted the spring pulls back the lever, and thus a step-by-step movement is given to the fork, which it transmits to the wheel G carrying the index.

Fig. 381.



The manner in which the battery-current is interrupted and renewed will be understood by reference to Fig. 379. The wheel R carries twenty-six teeth. On turning it by the button P, while the plate N is from its curved form in constant contact with the teeth, the plate M, being crooked, has its contact broken and renewed every time it passes over a tooth, and at the same time the battery-current is thrown off and on. Suppose the pointer P is advanced four letters, then the current between N and M will be four times made and four times broken, and the armature of the electro-magnet at the distant station will be four times attracted and four times pulled back by its spring; but these four attractions will give four movements to the wheel G, and the pointer will pass over the same number of letters in the dial of the receiver, Fig. 380, as in that of the manipulator, Fig. 379. At the top of the case of the instrument is the alarum, which is worked by a special electro-magnet.

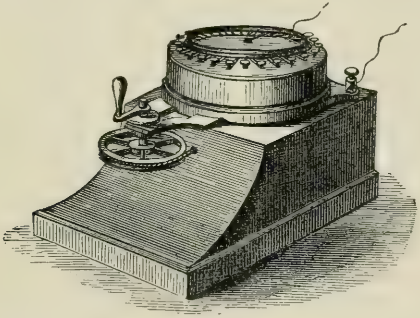
Referring now to Fig. 378, a series of twenty-eight ivory keys is seen in front of the apparatus; the first being marked with a cross, the last with an arrow, and the intermediate twenty-six with the letters of the alphabet—the first ten letters carrying also the ten numerals. Immediately in front of the keys, on a horizontal platform of mahogany, is the dial B, and two small metal pieces, *m n*, which are movable, and which by means of a handle may be brought into contact, *m* with *s* or *r*, and *n* with *q* or *p*. The dial B

is the verifier; its index must always point to the same letter as that last signalled; if it does not, it shows that the apparatus is not in proper working order. When *m* is in contact with *s*, the apparatus is in a condition to send signals from Paris to Rouen; when in contact with *r*, it is in a condition to receive a signal from Rouen to Paris. In like manner, when *n* is in contact with *q* the alarum may be sounded at Rouen; when in contact with *p*, the machinery is in a state to receive a notice from Rouen.

(267) **Wheatstone's Universal Dial Telegraph.**—This instrument, which is extensively used in the metropolis and elsewhere, both for public and private establishments, consists of two distinct parts—viz. the '*communicator*,' for sending the message, and the '*indicator*,' for receiving the same.

The *communicator* (Fig. 382) consists of a small box, upon the upper surface of which is a fixed dial, having its circumference divided into thirty equal spaces, marked with the twenty-six letters of the alphabet, the three points of punctuation, and a +, with an inner circle marked with the nine digits and a +, this series being repeated twice. A hand or pointer in the

Fig. 382.



centre of the dial is made to rotate by mechanism, and points severally, at the will of the operator, to the letters or figures required to be indicated. Round the circumference of this lettered disc are thirty small keys or buttons, which can be depressed by the finger, one for each letter or sign.

In its interior construction, the box contains a permanent horseshoe magnet and coil apparatus for producing the necessary magnetic currents. An exterior handle, revolved by the hand, or other means, causes an axis in the instrument to revolve. Attached to this axis are two equal arms, to the extremities of which, fixed perpendicularly, are two cores of soft iron. Round each of these cores of soft iron a helix of fine insulated copper wire is wound in a continuous length. The coils and armature are so arranged upon the axis as to be in close proximity with the poles of the horseshoe magnet, so that at every revolution of the axis with which the

handle is connected, the two soft iron cores of the coils pass over the poles of the magnet, and become temporary magnets by induction; and, at the moment of making and breaking contact with the poles of the magnet, induce currents of electricity, moving in opposite directions through the wire of the coils if the circuit be complete. This temporary magnetisation of the cores, and induced currents, taking place each time contact is made and broken during the revolution with the poles of the magnet, a succession of currents or waves of electricity may be obtained by the continuous revolutions of the handle attached to the axis carrying the armature.

The mechanism of the communicator is so arranged that when any of the thirty keys round the dial is pressed down by the finger, that key has the effect of cutting off the passage of the current along the line and through the instrument, and of making a short circuit with the earth so long as it remains depressed. When any other key is similarly depressed, a simple piece of mechanism causes the depression of this key to elevate the former key, open the electrical circuit, and allow the induced currents derived from the magnet to flow in succession through the instrument and along the wire to the distant station, until they are again interrupted and passed into the earth by the depressed key. This short-circuit contact is made by means of a loose carrier-arm attached to the axis which carries the pointer on the dial, and is thrown in or out of gear by the depression or elevation of the key. Motion is communicated to this axis by a bevelled wheel working into a pinion fixed to the axis carrying the armatures; the motion being so adjusted that for every separate current induced in the coils, the hand shall move one space or letter on the dial. The keys therefore, being depressed in succession, will each liberate one current, or thirty distinct currents, during an entire revolution of the hand round the dial—fifteen in one direction and fifteen in the opposite direction.

For every current transmitted (these currents being in succession in different directions), the index of the communicator, and those of the indicators at the near and distant stations, will simultaneously advance, step by step, until the letter opposite the depressed key is reached by the pointer. The instant this letter is reached, a short circuit is made by the carrier; the current no longer flows through the telegraph wire and the indicators, but passes into the earth until another key is depressed and the circuit is again opened, and so on in succession until any number of required signals or letters have been registered.

The *indicator* (Fig. 383), externally in appearance something like a watch, is placed on a small stand in any convenient position for observing the dial. The face of the instrument is spaced into thirty divisions, like the communicator, with its double circle of

letters and figures, and its movable hand or index. A step-by-step motion is imparted to this hand by means of an electro-magnetic apparatus, which consists of two permanent magnetic bars or needles fixed to an axis, and lying parallel between two small electro-magnetic coils with soft iron cores. These electro-magnets are so arranged, that when a current of electricity from the communicator passes through the coils, their armatures exercise a mutual attraction and repulsion on the poles or extremities of the magnetic needles, the effect of which will be to impart a backward-and-forward motion to the axis carrying the magnetic bars. Fixed to the end of this axis is a short vertical arm, carrying a small escapement-wheel of fifteen teeth, the axis of which carries the pointer on the dial, and to which a step-by-step motion is imparted by the rotation of the escapement-wheel working to and fro against fixed stops or pins.

Fig. 383.

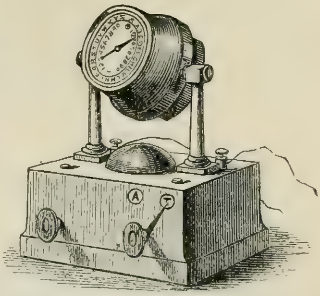
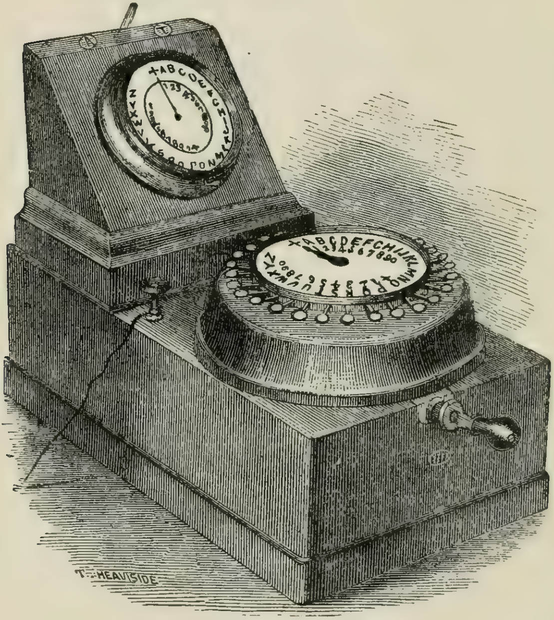


Fig. 384 shows the form which is now in general use. The stand of the indicator is furnished with a lever turnplate, by which the alarum A, for calling attention, or the telegraph T, can be thrown into circuit, according as the lever is turned to A or to T (Fig. 383).

Whenever the telegraph is not in use, the alarums at each end should be placed in circuit, so that on turning the handle of the communicator, and depressing a key, the first currents transmitted through the circuit will cause the bells at both ends of the line instantly to sound, and call the attention of the clerk or operator at the distant station, who immediately signifies his presence at the instrument to the sender by turning the handle of his communicator, depressing a key, and ringing both bells a second time. Both sender and receiver now throw the telegraph T into circuit, taking care to observe that the hands of both the communicator and indicator stand respectively at the + marked on the dials, which is necessary to ensure the correspondence of the letters about to be transmitted at both stations. The sender spells out his message by depressing, in succession, with his left hand, each key of his communicator corresponding with the required letters, while he steadily turns the handle of his instrument with his right hand.

The pointer of his indicator will also turn in succession to each of these letters, and pause until the next letter or key is depressed. The hand of the indicator of the receiver of the message at the distant station will also point to the same letter, spelling out the word required, the receipt of which he acknowledges by turning the handle of his communicator, depressing the key opposite the

Fig. 384.



+, and causing the hands of both indicators to pass through a complete revolution. If any letter or sign in spelling a word requires to be repeated in succession, it is only necessary to depress for an instant the preceding key, and then to depress that opposite the letter to be repeated, before the pointer of the communicator in its revolution has reached the letter.

For connecting up the instruments the following rules are to be observed:—

1. The instruments at each station should first be placed on short circuit, as shown in Fig. 385. Short wires are placed upon the terminals from *a* to

e, and from *d* to *f*, the switch *x* being turned to point to the letter T. The handle Z of the communicator is then to be turned steadily, at the rate of about 120 revolutions per minute, and the index or pointer passed from + to + on the dial by depressing the finger-key opposite the full stop (.), and the key opposite the + immediately afterwards. If the index of both communicator and indicator correspond, the connections will be right; but should the hand of the '*indicator*' be either in advance or behind the + one space, the connecting wires must be reversed, *a* being joined up to *f*, and *d* to *e*; the instruments will now be found to correspond in the revolution of their pointers round the dials.

Fig. 385.

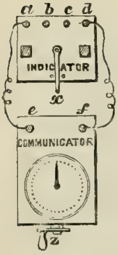
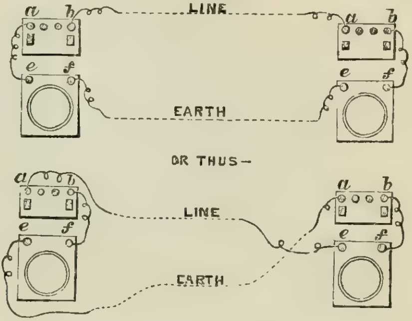


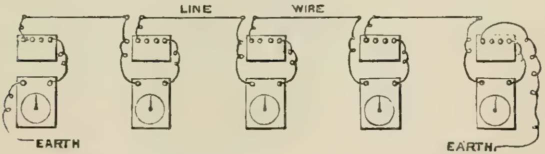
Fig. 386.



2. The instruments being in working order, the line-wire is connected to the instruments by removing one of the short wires at each station, and substituting the line-wire and earth-wire, as shown at *a e* and *b f*, Fig. 386. The same signal of passing the pointer from + to +, is now to be sent from station to station; and if the index at the other station falls either one in advance or behind the position of the line and earth, wires at *one station* only must be reversed.

3. When more than two stations require to be connected up in the same circuit, the above rules are to be observed with reference to the signals from + to + at each successive station, the connection appearing thus (Fig. 387):—

Fig. 387.



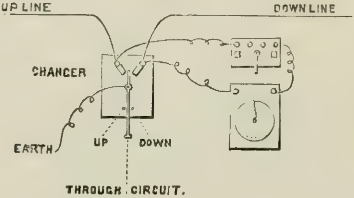
4. When several stations are in the same circuit, it will often be found convenient to introduce a switch or *current-changer*, enabling the operator to send up and down the line in either direction, without interrupting the

communication of those stations situated in an opposite direction to that in which he is speaking. The manner of connection will be seen by reference to Fig. 388. This arrangement will enable several stations to communicate with each other at the same time—

a —— *b* —— *c* —— *d* —— *e* —— *f* —— *g* —— *h*.

For instance, while *a* is speaking to *b*, *c* can talk to *d*, *e* with *f*, and so on. This sytsem requires that each station has its own signal or prefix for calling attention, and that when no station is called, either up or down the line, the handle of the current-changer remains on the *through circuit*, as shown in the figure :—

Fig. 388.



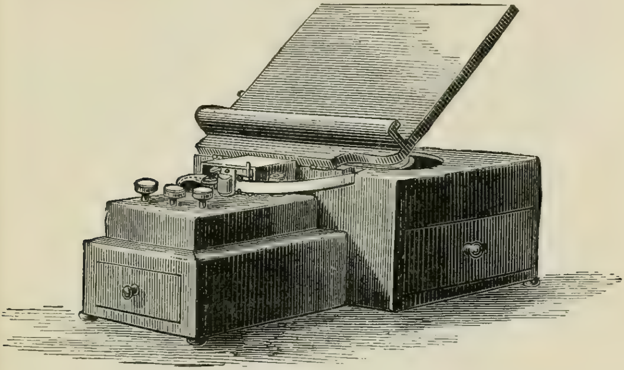
(268) **Automatic System for the Transmission of Telegraphic Messages.**—Since the speed of sending by hand is limited by the skill of the operator, Alexander Bain as early as 1843 invented a plan by which this could be done automatically. He punched the dots and dashes of the Morse alphabet in broad paper tape, and these holes were made to send the currents with immense rapidity. An admirable instrument for this purpose was subsequently invented by Wheatstone. It is thus described by him (*Comptes Rendus of the Paris Academy of Sciences*; and *Jurors' Report*, *International Exhibition* of 1862):—

'Long strips of paper are perforated by a machine, constructed for the purpose, with apertures grouped to represent the letters of the alphabet and other signs. A strip thus prepared is placed in an instrument associated with a source of electric power, which on being set in motion moves it along, and causes it to act on two pins, in such a manner that when one of them is elevated, the current is transmitted to the telegraphic circuit in one direction, and when the other is elevated it is transmitted in the reverse direction. The elevations and depressions of these pins are governed by the apertures and intervening intervals. These currents, following each other indifferently in these two opposite directions, act upon a writing instrument at a distant station, in such a manner as to produce corresponding marks on a slip of paper moved by appropriate mechanism.

'The first apparatus is a perforator (Fig. 389), an instrument for piercing the slips of paper with the apertures in the order required to form the message. The slip of paper passes through a guiding groove, at the bottom of which an opening is made sufficiently large to admit of the to-and-fro motion of the upper end of a frame containing three punches, the extremities

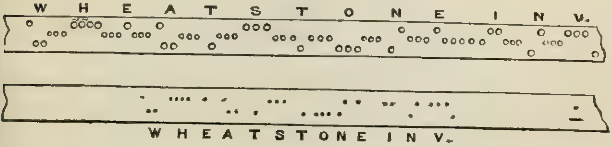
of which are in the same transverse line. Each of these punches, the middle one of which is smaller than the two external ones, may be separately elevated by the pressure of a finger-key.

Fig. 389.



'By the pressure of either finger-key simultaneously with the elevation of its corresponding punch, in order to perforate the paper, two different movements are successively produced: first, the raising of a slip which holds the paper firmly in its position; and secondly, the advancing motion of the frame containing the three punches, by which the punch which is raised carries the slip of paper forward the proper distance. During the reaction of the key consequent on the removal of the pressure the clip first fastens the paper, and then the frame falls back to its norma position. The two external keys and punches are employed to make the holes, which grouped together represent letters and other characters, and the middle punch to make holes which mark the intervals between the letters. The perforations in the slip of paper appear thus (Fig. 390):'—

Fig. 390.

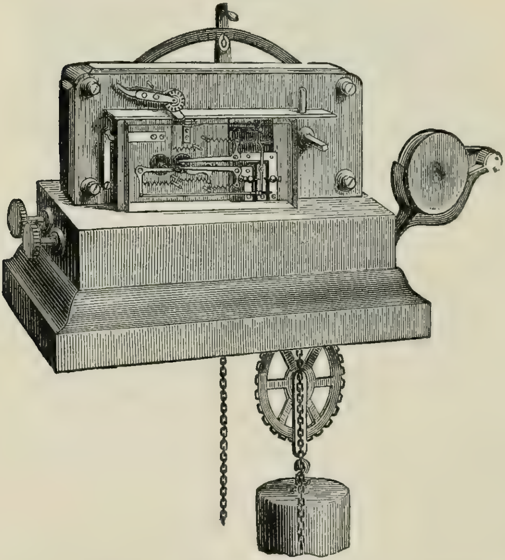


A very simple addition to the perforator enables a printed message which has been received to be retransmitted to a more distant station, without any translation or knowledge of the meaning of the message. The printed band which has been received is made to pass between two rollers, one of which is movable by a

finger-screw, so as to cause the characters to pass successively before the eyes of the operator. The keys of the perforator are acted upon with the right hand, and the finger screw with the left; as the characters successively appear, the keys are pressed down in the order of the points of which the letters consist, an operation which requires scarcely any skill to perform.

There need be no change in the alphabet which is at present employed; the points at one side may represent the short dashes, and those at the other side the long dashes, their order remaining the same as in the existing system.

Fig. 391.



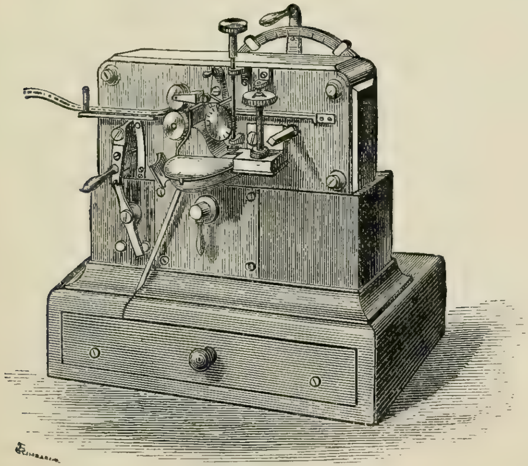
'The second apparatus is the transmitter (Fig. 391); the object of which is to receive the slips of paper prepared by the perforator, and to transmit the currents in the order and direction corresponding to the holes perforated in the slip. This it effects by mechanism somewhat similar to that by which the perforator performs its functions.

'An eccentric produces and regulates the occurrence of three distinct movements:—1. The to-and-fro motion of a small frame, which contains a groove fitted to receive the slip of paper, and to carry it forward by its advancing motion; 2. The elevation and depression of a spring-clip, which holds the slip of paper firmly during the receding motion, but allows it to

move freely during the advancing motion; 3. The simultaneous elevation of three wires placed parallel to each other, resting at one of their ends over the axis of the eccentric, and their free ends entering corresponding holes in the grooved frame. These three wires are not fixed to the axis of the eccentric, but each end of them rests against it by the upward pressure of a spring; so that when a light pressure is exerted on the free ends of either of them, it is capable of being separately depressed. When the slip of paper is not inserted, the eccentric is in action; a pin attached to each of the external wires touches, during the advancing and receding motions of the frame, a different spring, and an arrangement is adopted, by means of insulation and contacts properly applied, by which, while one of the wires is elevated, the other remains depressed; the current passes from the rheomotor to the telegraphic circuit in one direction, and passes in the other direction when the wire before elevated is depressed, and *vice versâ*; but while both wires are simultaneously elevated or depressed, the passing of the current is interrupted. When the prepared slip of paper is inserted in the groove, and moved forward whenever the end of one of the wires enters an aperture in its corresponding row, the current passes in one direction; and when the end of the other wire enters an aperture of the other row, it passes in the other direction. By this means the currents are made to succeed each other *automatically* in their proper order and direction, to give the requisite variety of signals. The middle wire only acts as a guide during the operation of the current.

'The wheel which drives the eccentric may be moved by the hand, or by the application of any motive power. When the movement of the trans-

Fig. 392.



mitter is effected by machinery, any number may be attended to by one or two assistants. This transmitter requires only a single telegraphic wire.

'The third apparatus is the recording or printing apparatus (Fig. 392), which prints or impresses legible marks on a strip of paper, corresponding in their arrangement with the apertures in the perforated paper. The pens or styles are elevated or depressed by their connection with the moving parts of the electro-magnets. The pens are entirely independent of each other in their action, and are so arranged that when the current passes through the coils of the electro-magnet in one direction, one of the pens is depressed, and when it passes in the contrary direction the other is depressed; when the currents cease, light springs restore the pens to their elevated points.'

The mode of supplying the pens with ink is the following :—

A reservoir about an eighth of an inch deep, and of any convenient length and breadth, is made in a piece of metal, the interior of which may be gilt, in order to avoid the corrosive action of the ink ; at the bottom of this reservoir are two holes, sufficiently small to prevent by capillary attraction the ink from flowing through them ; the ends of the pens are placed immediately above these small apertures, which they enter, when the electro-magnets act upon them, carrying with them a sufficient charge of ink to make a legible mark on a ribbon of paper passing beneath them. The motion of the paper ribbon is produced and regulated by apparatus similar to those employed in other register and printing telegraphs.

Wheatstone subsequently abandoned his 'single-needle' printing method and substituted the Morse alphabet, and this system is very largely used by the Post Office in England.

The advantages of the automatic over the key system are very great. No manual dexterity on the part of the operator could compete in rapidity with that obtained by the automatic process, which is only limited by the rapidity with which the recurring motions of the transmitter can be effected. Moreover, as the prepared messages may be transmitted with equal rapidity in whatever language the cypher may be, and as the perforated bands may be prepared at leisure, guarantees of accuracy are obtained which cannot be afforded by the system of immediate hand transmission. These advantages would be greatly increased if the messages could be prepared by the correspondents themselves, which they could easily be, if they would take the trouble of learning a telegraphic alphabet. Thus a merchant's clerk might prepare the messages of the firm in the punched paper required for Wheatstone's transmitter: this prepared paper, on delivery at the telegraph office, would simply have to be passed through the machine when its turn arrived, and the corresponding dotted tape received at the distant station could at once be addressed and be delivered, to be deciphered by the receiver at his leisure.

CHAPTER XVIII.

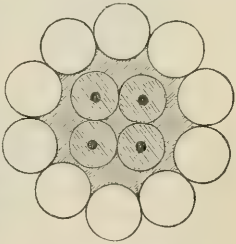
ELECTRIC TELEGRAPHY (*continued*).

SUBMARINE CABLES.

The Submarine Cable—Shallow-water Cables—Deep-sea Cables—The Conductor of the Submarine Cable—The Insulator—The Insulating Properties of Different Materials—The External Protection—Submersion of Submarine Cables—Accidents to Submarine Cables—The Electrical Properties of the Submarine Cable—Retardation of Signals—Electric Waves—Distribution of Electricity in Submarine Cables—Testing Cables—Thomson's Electrometer—The Quadrant Electrometer—The Syphon Recorder—Detection of Faults in Cables.

(269) **The Submarine Cable.**—1. *Shallow-water Cables.*—In 1840 Professor Wheatstone suggested to the Select Committee of the House of Commons on Railways the submersion of a submarine telegraph between Dover and Calais, and subsequently further developed his plans; but the first efficient submarine telegraph which was actually laid down, was the line between Dover and Calais projected by Mr. Brett, and completed by Mr. Crampton in 1851. In the year before, however, an uncovered gutta-percha wire was successfully laid, and communication was maintained for several hours; the wire was, however, destroyed by some fishermen. Portions of this wire have been very lately recovered, and both electrically and mechanically the gutta-percha was found to be in the highest condition after a submersion of fully twenty-seven years. The cable, a section of which is shown in Fig. 393, consisted of four copper conducting wires, No. 16 B.W.G. (0·065 inch diameter), each insulated with gutta-percha of No. 3 B.W.G., twisted together with a tarred-hemp covering, formed

Fig. 393.

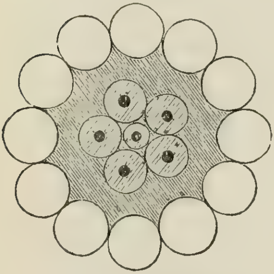


Dover and Calais.

into a rope, which was again served with tarred hemp, and protected with iron wires of No. 1 gauge. This cable, which weighed about 6 tons to the statute mile, was worked, with occasional injuries from anchors, till the spring of 1859, when extensive repairs were undertaken, in the course of which it was found that the gutta-percha covering of the copper wires was in as good order as when first laid—so complete had been the protection afforded by the tarred hemp and the immersion in water. Since 1859 this cable has been repeatedly broken and communication interrupted, but the repairs have been speedily accomplished. It has been found that for certain portions of the distance oxidation has set in, and many renewals have taken place, whilst in other portions the cable has remained uninjured and is still in excellent condition. The portion nearest to Dover has been entirely renewed. The facility of repair is now so great that the Submarine Company, who own this cable, have found it necessary, on account of the number of cables they possess, to build a repairing ship. This vessel has for years been constantly employed.

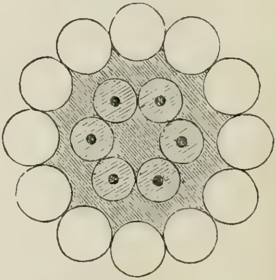
In 1853 a cable with six conducting wires, insulated by a double covering of gutta-percha, was laid between Dover and Ostend, shown in section in Fig. 394, very similar to the Dover and Calais cable, and weighing 7 tons per mile. Shortly after a

Fig. 394.



Dover and Ostend.

Fig. 395.

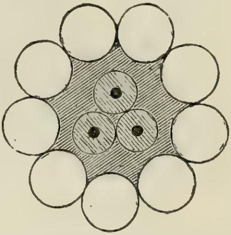


Donaghadee and Port Patrick.

cable, 25 miles long, was laid from Donaghadee in Ireland to Port Patrick in Scotland, across the Irish Channel; its weight was the same as that of the Dover and Ostend cable (Fig. 395). The Mediterranean cable, which is of the same size and construction as the latter was laid in 1854, from Spezzia to Corsica, a distance of 110 miles. This has since been recovered. In 1858 a line was laid between England and Hanover, 280 miles in length, containing

two conducting strands, and weighing 3 tons per mile. This cable was subsequently abandoned, only a small portion having been recovered. It was found impossible to repair it in consequence of its being deeply embedded in the sand. Two other cables were laid in 1859—one a very heavy one, between Folkestone and Boulogne, weighing $9\frac{1}{2}$ tons per mile, containing six conducting strands of copper wire, insulated with gutta-percha and Chatterton's compound. The principal ingredient of this compound is gutta-percha, with sufficient wood-tar and resin to give it proper consistency; it is applied by passing the wire through a vessel containing it, fitted with proper gauges, immediately before the die that puts on the gutta-percha; as the mixture becomes cold it hardens. The other cable was laid between England and Denmark: it was 350 miles long, weighed 4 tons per mile, and contained three conducting strands (Fig. 396). This cable has also been abandoned.

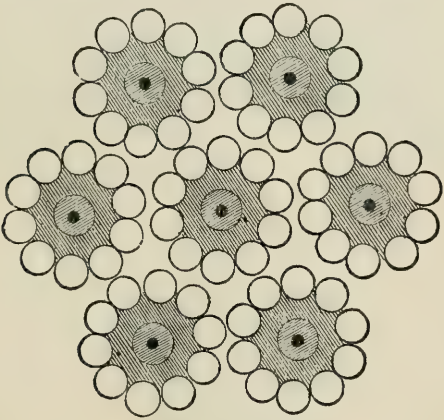
Fig. 396.



England and Denmark.

In the first four lines laid down by the International Telegraph Company, between Orfordness and the Hague, in 1853–4, four single wires were laid in four separate light cables. For a distance of four

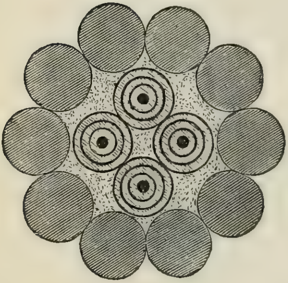
Fig. 397.



Orfordness and the Hague.

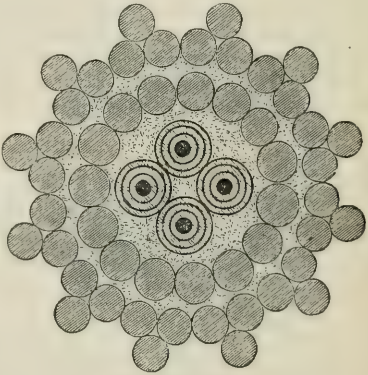
miles from each shore, where ships were thought more likely to drop their anchors, a large shore end was laid. As it was originally intended to lay seven cables, the shore end was formed of seven portions of the deep-sea cable laid up together, so as to form one large heavy cable, weighing about 15 tons to the mile. To this cable the four smaller ones were united. The core was double-covered gutta-percha wire wrapped with tape and yarn, externally, and covered with ten No. 8 galvanised iron wires laid on helically. These lines were so frequently damaged accidentally, and occasionally wilfully, that their repair required the almost constant services of a vessel and crew, kept for the purpose; and, therefore, to put an end to so serious an expenditure, a large cable with four conducting wires has been laid down in their stead, but between different points. The four-wire cable was, in the first place, laid from Dunwich to Zandvoort in 1859, but subsequently the

Fig. 398.



Lowestoft and Zandvoort. Deep sea.

Fig. 399.



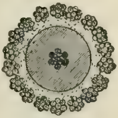
Lowestoft and Zandvoort. Shore end.

English end was removed to Lowestoft, from which place a second four-wire cable subsequently was laid to the same place in Holland.

2. *Deep-sea Cables.*—Proposals having been made by Mr. Cyrus Field to cross the Atlantic with a cable, experiments upon the form of cable best suited for the deep-sea purposes were made at Messrs. Glass and Elliot's works. The form selected, a section of which is shown in Fig. 400, was calculated to bear three tons. It consisted of a strand of seven copper wires, each No. 22½ gauge, weighing 93 pounds per mile, covered with three coats of gutta-percha, weighing 227 pounds per mile, served with threads of jute yarn, saturated

with a composition of tar and other materials, and coated with eighteen strands of iron wire, each strand containing seven wires each of No. 22 gauge. The manufacture of this cable was commenced in February 1857, and the entire length (2,500 miles) was finished in July of the same year. The summer having been very hot, and the cable exposed, it became partially injured. A considerable variation in the conductivity of the copper wire was observed during the process of testing.

Fig. 400.



Section of Atlantic Cable, 1857.

The expedition for laying this cable left Valencia on August 7, 1857, and the cable continued to be successfully paid out until the 11th, when it broke in 2,000 fathoms of water, after about 335 miles had been laid. The dynamometer, at the time the cable parted, indicated a strain of 35 cwt. On examination, it was found that the cable was injured either by coiling or uncoiling, or by the original exposure to heat, and the amount of leakage was high.

In the spring of 1858, two unsuccessful attempts were made to lay the cable, but it was successfully accomplished in the summer of the same year, between July 17 and August 5, and several messages were sent through it. On September 1 intelligible signals ceased to be received.

'We attribute the failure of the enterprise to the original design of the cable having been faulty, owing to the absence of experimental data; to the manufacture having been conducted without proper supervision; and to the cable not having been handled after manufacture with sufficient care. We have had before us samples of the bad joints which existed in the cable before it was laid, and we cannot but observe that practical men ought to have known that the cable was defective, and to have been aware of the locality of the defects before it was laid.'[1]

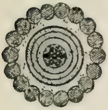
The Channel Islands telegraph was laid from Portland to Alderney, Guernsey, and Jersey in August 1858. It consisted of four strands of copper wires forming one conductor, covered with gutta-percha, and protected by iron wires, the weight being about $2\frac{1}{2}$ tons per mile; the length was 93 miles, and the depth of the water is nowhere greater than 60 fathoms. In the month of February 1859, this cable was broken at Jersey by being chafed against the rocks in a violent gale. Another accident occurred to it eight months after it was laid, four miles from the island of Portland, where the tide had caused it to work upon a ridge of rock in 25 fathoms of water, which had worn it through. This cable was subsequently abandoned from the expense involved in

[1] Report of the Joint Committee appointed by the Board of Trade and the Atlantic Telegraph Company, 1861.

its maintenance, but cables have been since laid between Dartmouth and Guernsey, Jersey, and Alderney, which are now the property of the British Government.

The Red Sea and India Telegraph Company was formed in 1857–8. The cable consisted of a strand of copper wires (Fig. 401), weighing 180 pounds per nautical mile, covered with two coats of gutta-percha, alternated with two coatings of Chatterton's compound, weighing 212 lbs. per nautical mile. The core was served with hemp-yarn tarred, weighing $1\frac{1}{2}$ cwt. per nautical mile, protected by iron wires weighing 16 cwt. per nautical mile. This cable had, consequently, the largest copper conductor, and the best insulation, of any cable made up to that date. The whole length of the line was 3,043 nautical miles. The cable was laid in three sections: the first, from Suez to Cossire, 255 nautical miles in length; the second, Cossire to Suakin, 476 miles; the third, from Suakin to Aden, 629 miles. This cable worked for nine months, and then failed a few days before a second section was completed from Aden to India. It was not tested under water after manufacture, which fact, together with the lightness of the protecting iron wires and the tightness with which it was laid, are sufficient to account for its failure.

Fig. 401.



Section of Red Sea Cable.

The cable laid in shallow water between Singapore and Batavia for the Dutch Government, which weighed 21 cwt. per mile, was similar in construction to the Red Sea cable, which had been devised for a deep-sea line; in these cables the interstices between the wires were left vacant. This cable did not last long. The cable has been replaced by one laid for the Eastern Telegraph Company. The Tasmanian cable, manufactured by Mr. Henley, and laid across Bass's Straits in 1859, in three sections, weighed two tons per mile; one section failed, and had to be replaced by a stronger cable.

In 1854 a submarine cable with six conducting wires was laid from Spezzia to Corsica, and in the following year, after two unsuccessful attempts by Mr. Brett, Mr. Newall laid a cable with four conducting wires, and weighing 3 tons per mile, between Cape Spartivento and Bona, in Algeria, a distance of 125 miles. This has since failed. Sections of this cable are shown in Figs. 402 and 403.

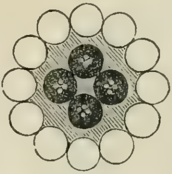
In 1857 the Mediterranean Extension Company laid cables from Cagliari (Sardinia) to Malta, and from Malta to Corfu. The line consisted of a strand of copper wires forming one conductor, covered with gutta-percha, and protected by a serving of tarred yarn covered with iron wires. The cable weighed 18 cwt. per mile. The line from Cagliari to Malta worked well for twelve months,

when a fault occurred; this fault was repaired, and the line worked again for several weeks, when it again failed. The line between

Fig. 402.

Cape Spartivento and Bona.
Deep sea.

Fig. 403.



Cape Spartivento and Bona.
Shore end.

Malta and Corfu was laid in depths extending to nearly 2,000 fathoms; it remained in good working order for about a year and three-quarters, and then suddenly broke down. Communication between these points has subsequently been obtained by other routes.

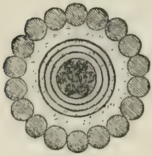
Lines between the Dardanelles, Syra, Candia, and Athens have been laid by Mr. Newall; and between Spain, Majorca, and Minorca by the Spanish Government, manufactured by Mr. Henley. The cable between Toulon and Algiers was manufactured by Messrs. Glass and Elliot. It consisted of a strand of copper wire, weighing 400 lbs. per mile (Fig. 404), covered with four coats of gutta-percha, alternated with four coats of Chatterton's compound, also weighing 400 lbs. per mile, served with tarred rope, and protected by steel wires, covered with hemp to prevent their corrosion. The diameter of the complete cable was 0·8 inch. This cable has since failed and been replaced by another. The core of the Malta-Alexandria cable (Figs. 405, 406, and 407) consisted of a strand of seven copper wires, weighing 400 lbs. per nautical mile, covered with three coatings of gutta-percha, alternated with three coatings of Chatterton's compound, also weighing 400 lbs. per nautical mile. This core was served with hemp, saturated with tar, and covered with eighteen No. 11 iron wires, for the deep-water portion, the shore end being covered with No. 0 iron wires. The line, as originally devised, was to have been laid between England and Gibraltar, where for 300 miles depths of from 1,500 to 2,500 fathoms would be encountered, and the covering for this portion was to have been of steel wires, each coated with hemp. When the Gibraltar line was abandoned, the steel and hemp covering was given up, and the iron covering was

Fig. 404.

Section of Toulon and Algiers Cable.

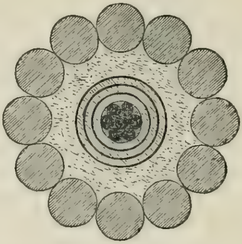
adopted for the whole cable. It was determined to lay it between Malta and Alexandria. The core was manufactured at the Gutta-percha Company's Works, and was tested in water up to a pressure of 600 lbs. per square inch, the air being exhausted from the tank before the water was turned in. The resistance and insulation of

Fig. 405.



Malta-Alexandria. Deep sea.

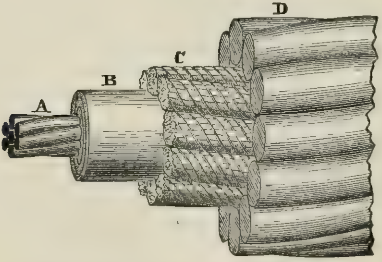
Fig. 406.



Malta-Alexandria. Shore end.

each mile of the cable were noted, and a careful system of comparative tests framed. This cable, belonging to the English Government, was laid in three sections: Malta to Tripoli, Tripoli to Benghazi, Benghazi to Alexandria. It lasted for some years, but frequent faults showed themselves, necessitating the presence of a repairing ship. Subsequently (1867), on the laying

Fig. 407.



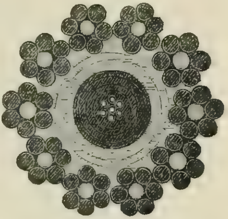
Malta-Alexandria Cable. Longitudinal view.

of a cable direct from Malta to Alexandria, the cable was abandoned, as much of it as possible being recovered. Since then a second direct cable has been laid between the same points.

In 1865 Mr. Cyrus Field's energy resuscitated Atlantic telegraphy. It was determined to try another cable, whose conductor was formed of seven copper wires, six round one (Figs. 408 and

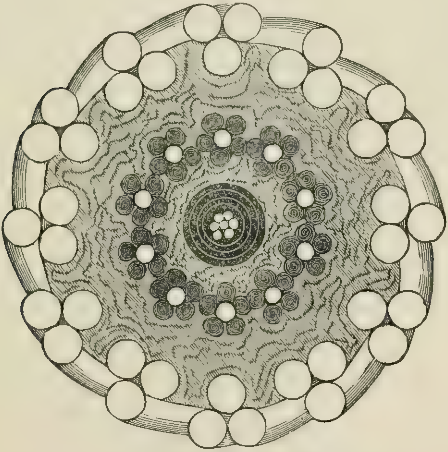
409); the conducting power of the wires was carefully examined, and none having a less capacity than 85 per cent. of that of pure copper was used.[1] The centre wire was first covered with Chatterton's compound so thickly, that when the other six wires forming the strand were laid spirally round it, every interstice became filled, and air excluded. The conductor thus formed, next received another coating of Chatterton's compound, and was then surrounded with a coating of the purest gutta-percha, which passed round it in a plastic state by means of a very accurate die, and sheathed the whole in a continuous tube. Over this was again laid another coating of Chatterton's compound, to this succeeded a second coating of gutta-percha, then another coating of Chatterton's compound, and so on alternately until the wire was covered with four coatings of gutta-percha and four of the compound.

Fig. 408.



Atlantic Cable, 1865.
Deep sea.

Fig. 409.



Atlantic Cable, 1865. Shore end.

[1] For many years now the conductivity of the copper used for submarine cables has been fixed at a minimum of 93 per cent. of pure copper, and this is often exceeded.

The whole conductor was immersed in water at 75° Fah., in which it remained for twenty-six hours, during which time it was constantly submitted to electrical tests. The perfect character of the insulation having been proved, the core was carefully wrapped with jute, which had been submitted to the action of catechu, and as fast as the wrapping proceeded it was coiled in water, in which, not only at this stage, but ever afterwards, till finally deposited in the sea, the cable was stowed. The wrapping was surrounded, spirally, by ten wires, manufactured from homogeneous iron, each separate wire being itself, in the first instance, covered with tarred Manilla yarn, by which the iron was protected, and the specific gravity of the mass lessened.

The 'shore end' of the Atlantic cable was the largest at that time ever constructed (Fig. 409). The core was formed by the main cable, which was wrapped with a serving of yarn to a size sufficient to receive around it twelve strands of iron wire, each strand being composed of three galvanised iron wires, each nearly a quarter of an inch in diameter. The weight of the completed shore end was nearly 20 tons to the mile. Its diameter was 2½ inches, but at its junction with the main cable it was made to taper down to the size of the latter by a gradual diminution in diameter extending over 500 yards. The shore end was laid out for about 28 miles from the coast of Valentia Island, where it reached water of the depth of 100 fathoms. The weight of the deep-sea cable, according to the company's statement, in air, was 35 cwt. 3 qrs. per nautical mile of 2,028 yards, and its weight in water 14 cwt. to each nautical mile, being only a fraction heavier in that medium than the old cable, though bearing more than twice the strain—that is to say, it would bear its own weight in 11 miles deep of water. Its breaking strain was 7 tons 15 cwt. The length of cable shipped on board the Great Eastern was 2,300 nautical miles; the actual distance from the point of departure, Valentia, on the west coast of Ireland, to the terminal point, Heart's Content, in Trinity Bay, Newfoundland, on which it was to have been landed, being 1,670 nautical miles.

As the cable was finished, it was received into enormous iron water-tanks, constructed for the purpose at the works, at Morden Wharf, Greenwich, at the rate of about 80 miles per week. As the tanks became full, their contents were transferred to tanks placed on board the Amethyst and Iris, by which vessels they were conveyed to the Great Eastern, lying in the Medway. The great steamship was fitted up with three tanks to receive the cable, one situated in the fore hold, 51 feet 6 inches diameter, by 20 feet 6 inches in depth, its capacity being for 693 miles of cable; one situated nearly amidships, 58 feet 6 inches broad, and 20 feet 6 inches deep,

holding 899 miles of cable; and one situated in the after hold, 58 feet broad, and 20 feet 6 inches deep, and contained 898 miles; these three tanks were, therefore, capable of containing in all 2,490 miles of cable.

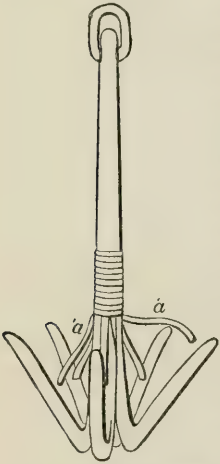
The great ship commenced paying out the cable on the evening of July 23, 1865. At 3.15 A.M., on the morning of the 24th, when 84 miles of cable had been paid out, Thomson's Marine Galvanometer (146), the instrument used in the system employed in testing, showed a serious fault, which, discovered at 9 A.M. on the 25th, was found to have arisen from a piece of wire of the same kind as that used in the protecting strands of the cable itself having been forced through the outer covering of the cable into the gutta-percha so as to injure the insulation. Measures were at once taken to make a new joint and splice, the cable that had been picked up being rejected, as a good deal of it had been strained in the process. After a detention of some twelve hours, the paying out machinery was again put in motion, but not more than half a mile had been paid out when suddenly all communication between the ship and the shore ceased; no fault had, however, occurred, the interruption in the signalling being accounted for by the electricians by the supposition that the order of the tests had become deranged whilst the splices were being made on board. After a detention of 37 hours, the operation of paying out the cable was resumed. After about 716 nautical miles had been paid out, 'dead earth' was found, or, in other words, there was a complete destruction of insulation, and an uninterrupted escape of the current into the sea; the injury was close to the ship, and proved to have been occasioned by a piece of iron wire, 'bright as if cut with nippers at one end, and broken off short at the other,' driven right through the centre of the coil so as to touch the inner wires; this wire was found to have the same thickness as the wire used in making the protecting cover of the cable.

In the early morning of August 2 (about 8 A.M.), when within a few miles of the very deepest part of the Atlantic plateau, another bad fault was detected, and as the cable was being slowly picked up it parted, in latitude 51° 25′, longitude 39° 6′, 1,062·4 miles from Valentia, and 606·6 miles from Heart's Content. Several attempts were made to recover the cable, but without success; and the attempt was abandoned until the following year. It was confidently believed that the cable, although resting at a depth of about two miles, could be recovered with proper apparatus, and immediately after the return of the expedition final measures were resolved upon for the next year's operations. It was determined to make an additional amount of cable sufficient to lay a

second cable across the Atlantic. This cable was essentially the same as the other, with the exception that the Manilla hemp was *not* tarred, but soaked in a preservative. Arrangements were made also for a complete system of apparatus for grappling the lost cable. In 1866, on the completion of the shipping, the Great Eastern, accompanied by other vessels, started, and first commenced by paying out the new cable (known as the 1866). This, with the exception of a slight accident, was successfully accomplished, and the American end was safely landed at Heart's Content, Newfoundland, on July 27. The insulation of the cable was perfect, and the successful issue of the event was a matter of great congratulation.

The expedition then started for the recovery of the lost cable of the previous year. The cable was eagerly sought for, and so exact had the observations been taken to identify its position that the cable was actually hooked on August 10, but, owing to inclement weather, difficulties were encountered, and it was not until September 1, after much engineering skill had been shown, that the cable itself was brought on board the Great Eastern, when it was found to be electrically perfect. Fig. 410 shows the grapnel used for the purpose, fitted with springs to prevent the cable swinging from the grapnel-flukes when hooked. Fig. 411 shows the manner in which the cable was finally recovered. The cable was first hauled up at the point A and buoyed. It was then caught again, and lifted at C by the Great Eastern, whilst another vessel—the Medway—hooked it further on, and putting on rapid and great strain, broke the cable. It was then easy for the Great Eastern to bring the cable above water. The grapnel-rope used for the occasion consisted of a combination of steel wire and hemp strands spun together, measuring $2\frac{1}{2}$ inches in diameter, and formed of seven smaller ropes; it was calculated to bear a strain of 30 tons. The great success of the expedition was principally due to Captain Moriarty, R.N., for his navigation, and to Sir Samuel Canning for his great engineering skill.

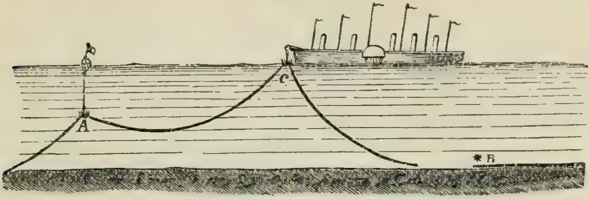
Fig. 410.



(270) A cable to be laid in a deep sea must of course be strong, both absolutely and relatively to its weight in water;

it must be light, or the great lengths required cannot be conveniently carried; it must not be liable to stretch, and it must

Fig. 411.



coil well, and be paid out easily. The lighter forms of cable used first for deep seas—as, for example, the Red Sea cable and the first Atlantic—were generally successfully laid, but were not permanently successful, communication generally ending within a year; the principal causes of failure being bad guttapercha joints, bad copper joints, injuries to the insulator before the cable was laid, high battery power burning small faults into big ones and eating away the copper, and lightning, from which they were often unprotected.

Among the proposed forms of deep-sea cables may be mentioned Allan's, shown in section in Fig. 412, and in longitudinal view in Fig. 413. The principal feature of this cable is the ab-

Fig. 412.

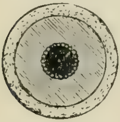
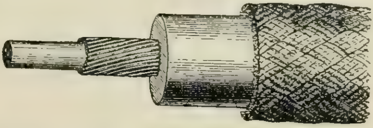


Fig. 413.



sence of an outer covering of wire, the guttapercha-covered wire being strengthened by a layer of small steel wires round the copper conductor, which is 0·114 inch in diameter, and weighs 240 lbs.

Fig. 414.

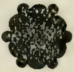
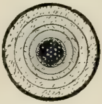


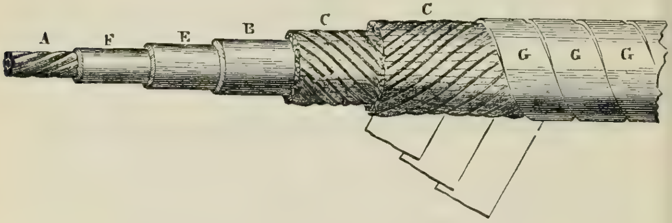
Fig. 415.



per knot. The steel wires, 19 in number, are 0·02 inch in diameter, weighing about 120 lbs. per knot. Allan's cable has, however, never had any practical trial.

Siemens' cable, a section of the copper conducting core of which is shown in Fig. 414, a section of the cable itself in Fig. 415, and a longitudinal view in Fig. 416. In this cable iron wires are omitted altogether, and another material, considered more durable, is sub-

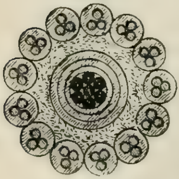
Fig. 416.



stituted. The core is surrounded with two layers of hempen strands C C (Fig. 416), laid on under considerable tension. Three or more strips of copper or brass G G, about 0·01 inch thick, are then bound round these strands, while they are still stretched by the tension; and this copper or brass sheathing grips the hempen cords tightly, so that they cannot contract longitudinally after leaving the machine. By this construction, a cable is obtained which is extremely light and strong; thus a cable $\frac{3}{8}$ inch diameter bears a strain of 15 cwt. before breaking, and stretches only 0·8 per cent. its length under a load of half the breaking strain. The weight of the copper conductor of this cable is 550 lbs. per knot, the diameter of the core 0·52 inch, and that of the completed cable 0·75 inch.

As a protection against rust, Chatterton proposed to cover each of the outer wires separately with gutta-percha. A cable of this make is shown in section in Fig. 417, with strands composed of three iron wires instead of single wires in the sheath; and, except on the score of expense, it seems well adapted to the purpose. It has been proposed also to protect the iron wires by vulcanite applied either as a general coating or to each wire separately. The two cables laid across the Atlantic in 1865 and 1866 have since failed and have been abandoned, but four others have been laid and are now successfully working.

Fig. 417.



Chatterton's Cable.

It would be impossible to describe the various cables which have been laid since the preceding, but at the present time this country is connected by submarine telegraphy with the rest of the world.

More cables have been laid across the Atlantic; connection has been made with India and Australia by cables from our south coast to Gibraltar and Alexandria, from Suez to Aden and Bombay, and from Madras to Singapore (to China and Australia). South America has been brought into close communication by means of the cables from Lisbon to Madeira and Pernambuco, whence cables coast the whole way along the Brazils to Buenos Ayres. The cables on the Chili or west coast are brought into connection by the subterranean line across the Andes.

(271) **The Conductor of the Submarine Cable.**—The best material, and the one that has been always used, is copper. Iron, though cheap and strong, has so low a conductivity that its sectional area must be increased five or six times—that is, five or six times the weight of material has to be employed—to bring its conducting capability up to that of copper. But the conductivity of copper is affected in a surprising manner by the presence of foreign substances, as is shown by the following table by Matthiessen.

Substances Alloyed with Pure Copper	Conducting Power of Alloy, Pure Copper being 100	Temperature, Centigrade
Carbon—		
Copper with 0·5 per cent. of carbon	77·87	18·3°
Sulphur—		
Copper with 0·18 per cent. of sulphur	92·08	19·4
Phosphorus—		
Copper with ·13 per cent. of phosphorus	70·34	20·0
„ ·95 „ „	24·16	22·1
„ 2·5 „ „	7·52	17·5
Arsenic—		
Copper with traces of arsenic	60·08	19·7
„ 2·8 per cent. of arsenic	13·66	19·3
„ 5·4 „ „	6·42	16·8
Zinc—		
Copper with traces of zinc	88·41	19·0
„ 1·6 per cent. of zinc	79·37	16·8
„ 3·2 „ „	59·23	10·3
Iron—		
Copper with ·48 per cent. of iron	35·92	11·2
„ 1·66 „ „	28·01	13·1
Tin—		
Copper with 1·33 per cent. of tin	50·44	16·8
„ 2·52 „ „	33·93	17·1
„ 4·9 „ „	20·24	14·4

Substances Alloyed with Pure Copper	Conducting Power of Alloy, Pure Copper being 100	Temperature, Centigrade
Silver—		
Copper with 1·22 per cent. of silver . . .	90·34	20·7
„ 2·45 „ „ . . .	82·52	19·7
Gold—		
Copper with 3·5 per cent. of gold . . .	67·94	18·1
Aluminum—		
Copper with 10 per cent. of aluminum . .	12·68	14·0

The addition of a small quantity of lead, or of tin (0·1 per cent.), to copper containing suboxide obtains a purer metal, and consequently improves its conducting power.

Different commercial coppers vary also greatly in their conducting power. Thus pure copper being 100, Matthiessen found—

Spanish (Rio Tinto) to be	14·24	at 14·8°	Cent.
Russian . . .	59·34	„ 12·7	„
Australian . . .	88·86	„ 14·0	„
American . . .	92·57	„ 15·0	„
Bright Copper Wire .	72·27	„ 15·7	„
Tough Copper . .	71·03	„ 17·3	„

It appears from this table that Rio Tinto copper possesses no better conducting power than iron. Of the various impurities present in commercial coppers, the suboxide of copper appears to be the most injurious, the conducting power of the metal being diminished by it in one case as much as 28 per cent. There is no substance which, when added to copper, increases its conducting power, and it is scarcely practicable to obtain the metal perfectly pure; nevertheless, it is highly important that the best and purest should be used in submarine cables. An increase of 10 per cent. in the conductivity of the metallic core of a cable is equivalent to an increase of 10 per cent. in the number of messages that may be transmitted through it in a given time. The conductor of a cable is not usually a single solid wire, but a strand of several wires (from three to seven). This entirely removes the serious defect to which a solid wire would be liable, that, namely, of breaking after being bent a few times; and as conduction takes place through the mass, and not along the surface, a strand and a solid wire of equal weights are equally good conductors. The joints of the

conductor are made by soldering together two filed and fitted ends; this joint is wrapped round with fine copper wire to strengthen it, and solder is again run round this wire; a second wrapping of fine copper is then applied and left without solder.

When the current from the battery escapes from a hole in the insulator into the sea, chemical action is set up, and soluble chloride of copper is formed; the metal is thus gradually eaten away, and metallic continuity interrupted. The current from the negative end of the battery tends to the formation at the fault of the alkali soda, which causes a greater leakage by enlarging the hole in the gutta-percha. Mr. Varley has proposed to maintain the metallic continuity by twisting up a fine platinum wire with the copper strands of long cables.

The conducting power of the copper wire intended for the core of the cable is determined by means of Wheatstone's *parallelogram* or bridge (110), with which measurements can be made without an error of one part in 100,000, and the resistance of all wires compared with the standard unit.

The following are some of the points to be attended to in measuring the resistance of conductors (*F. Jenkin, Cantor Lectures*). All the resistance coils should be wound double, so that the current may pass both ways round the coil equally; this prevents self-induction, a disturbing element. Care must generally be taken in using the Wheatstone bridge to connect first the battery, and then the galvanometer. The battery must be left connected for the shortest possible time, to avoid heating the wires; special precautions must be taken to avoid resistances at connections, which are often considerable. The resistance of the wires composing the balance should not differ too greatly from that to be measured: short-wire galvanometers answer best for short wires; long-wire galvanometers for long wires. One cell of large surface generally gives better results than large batteries; the temperature of the wire to be measured, and that of the resistance coils, should be accurately observed. Practically, the copper of a cable is tested before it is used, to ascertain whether its quality is equal to that specified. When a knot of wire is covered, it is again tested for resistance, to insure that the proper quantity and quality of wire has been used; finally, after the cable is covered, the resistance test serves to check the length of the cable in circuit, to insure that the conductor is in no point interrupted, and that the temperature in the tank is not higher than it should be.

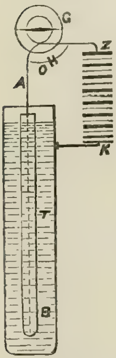
(272) **The Insulator.**—The object of surrounding the conducting wire of the submarine cable with an insulating substance is to prevent any serious proportion of the voltaic current from

being diverted to the sea near the conductor. The insulator acts the part of the pipe directing and containing the current; the copper core acts more nearly the part of the vacant space, allowing the current to pass, and retarding it only by friction. But no material known except dry air will *perfectly* contain electricity; some leakage, indicated by a current, always occurs; but the relative resistance to conduction with equal bulks of gutta-percha and copper is as

$$60,000,000,000,000,000,000, \text{ or } 6 \times 10^{19} \text{ to } 1.$$

A better idea of the vastness of this number will be obtained by observing that light would take a *century* to travel through the number of feet which that number would express. The practical effect of this degree of insulation with the Atlantic core is that more than $99\frac{1}{2}$ per cent. of the current leaving England would reach America; any improvement in insulation will therefore only go to diminish this half per cent. loss, in itself of no consequence whatever. India-rubber has a higher resistance still. The chief advantage of a high resistance is the facility it affords for detecting faults. The simplest test of the soundness of an insulator is to connect one end of the conductor A (Fig. 418) with one pole of a battery, Z, the other pole of which is joined to the water surrounding the insulated wire in the tank T. If a galvanometer, G, be placed between the battery and the conductor, and the other end of the conductor insulated, any current producing a deflection in the galvanometer must pass through the sheath from the copper to the water. Such a current is often called a *leakage*. With a battery of known strength, and a galvanometer with which the observer is already well acquainted, the greater or less deflection of the galvanometer needle will often be sufficient to show whether this leakage is so excessive as to indicate a flaw in the insulator connecting the water with the copper. The test is a rude and imperfect one, but it may be made to express with some accuracy the resistance of the insulator in the same units as those used for the conductor (see *Fleeming Jenkin's Cantor Lectures on Submarine Telegraphy*, lecture iv.; *Journ. Soc. Arts*, Feb. 23, 1866).

Fig. 418.



(273) **The Insulating Properties of Different Materials.**—1. *Gutta-percha.*—When pure and dry, this is one of the best insulators known, but as a material for covering a conductor

it has serious defects in practice; it gets soft by heat, and is then readily injured; it absorbs oxygen from the air, and becomes converted into a brittle resin, which easily cracks. This change goes on in dry earth, and to a certain extent in fresh water but apparently not in *salt* water, as gutta-percha which has remained in salt water for nearly thirty years has been found quite unchanged (269). A cable which has been properly and carefully tested before and during submersion should not afterwards exhibit any electrical fault. Lightning has frequently occasioned the destruction of cables; but it is now invariably the custom to attach lightning conductors to each end of a cable, however short. The various lightning conductors attached to the British cables are frequently examined, and they constantly show that they have arrested lightning. Gutta-percha is easily perforated even by sparks from an electrical machine, and a battery of 500 cells will do the same in a few minutes. But the manufacture of gutta-percha has been greatly improved of late; the special varieties prepared by the Gutta-percha Company almost rival india-rubber in insulating power, and possess a specific inductive capacity 25 per cent. less than the ordinary gutta. A mixture of alternate layers of gutta-percha and Chatterton's compound is an extremely perfect insulator, but it has the disadvantage of softening by heat, so that it will not stand hot climates. When gutta-percha is mixed with imperfectly conducting substances, such as pounded cocoa-nut shell, or in the material known as Godefroy's compound, the effect is, according to Wheatstone's experiments (*Report of Submarine Telegraph Committee*), greatly to reduce the insulation and to increase the induction; so also the interposition of cotton between two layers of gutta-percha, as in Hearder's cable, is, according to the same authority, equally disadvantageous. A most successful improvement has been introduced of late years by Mr. Willoughby Smith into the manufacture of gutta-percha, which has resulted in the reduction of its ' inductive capacity about 20 per cent. This in connection with long submarine cables is of great advantage, for, whilst admitting of a large increase in speed, it requires a smaller quantity of the insulating material. A great number of cables have been made with this material. Its insulation is, however, not so high as the ordinary gutta-percha.

2. *India-rubber.*—From its cleanness and purity, its high non-conducting power, and its low specific inductive capacity, this is admirably adapted for telegraphic purposes. It bears a temperature of 212° with impunity. There are two varieties of india-rubber met with in commerce. The East India gum, which is the cheaper, is apt to become sticky by exposure to the air, and is not

therefore adapted for telegraphic purposes; the Para gum, the well-known bottle india-rubber, is much more durable, and is an excellent insulator. The substance known as *vulcanised* india-rubber—a term applied to a mixture of india-rubber and sulphur—exists in two very distinct forms, viz. highly elastic, and in the form of a hard, black, brittle substance, capable of taking a high polish, and known under various names, such as *vulcanite*, *ebonite*, and *carbonised caoutchouc*. If not adulterated with conducting substances, it is in all forms a highly perfect insulator, and in the form of vulcanite it is not inferior to pure caoutchouc. It is fast superseding ivory and glass for electrical purposes and for electrical machines. It does not readily attract moisture to its surface, like glass; but when exposed to the weather, it constantly gives off sulphur, and its surface in the course of time becomes porous and absorbs water; were it not for this defect, it would be of great value for telegraphic insulation. The elastic variety is permanent under water, though not at all durable when exposed to the weather.

3. *Hooper's Core.*—This is a form of vulcanised india-rubber which has met with a large amount of success. The core is made by first lapping around the conductor one or more fillets of masticated india-rubber, over which a lapping of india-rubber compounded with oxide of zinc and French chalk is applied, and finally over this a third lapping of a similar mixture, or with oxide of lead, mixed with sulphur. The whole is tightly bound with a fibrous covering.

When this core is submitted to a steam heat of 240° Fah. to 280° Fah. for a few hours, the effect of the lower heat is to consolidate the several coatings, so that they completely unite together, and during the process, as the heat rises above 240° Fah., the outer coating becomes vulcanised, and parts at the same time with a portion of its sulphur, which permeates the inner coatings and effects their partial vulcanisation.

The specific gravity of this core is about 1·17, but will of course vary with the proportion of separator or vulcanising compound. The specific gravity of these compounds is about 1·20.

The insulation of these wires varies with their state of vulcanisation. The action of the sulphur on the copper conductor is counteracted by a coating of tin, which is applied by drawing the wire through it whilst in a molten state.

The tinning of the wire was found by Mr. Warren to increase the conductivity of the same nearly 2 per cent. This was afterwards verified by Sir William Thomson. No explanation has

been given to account for this singular result, which certainly is not without importance.

According to Mr. Latimer Clark, the inductive capacity of this core is 2 or 3 per cent. less than that of Mr. Willoughby Smith's improved gutta-percha. The experience gained in the manufacture of some thousands of miles of this core shows that, when properly manufactured and laid, it may be said to have well sustained its character as a fair and successful rival to gutta-percha for the purposes of submarine telegraphy.

It is, however, much to be regretted that a source of serious prejudice to this core has arisen from the laying of some recently made cables, which had been designed for deep water, in shallow water, and where, from strong currents and the nature of the bottom, the cable has been completely chafed through.

A cable containing this core, laid for the Cuba Submarine Company during the summer of 1874 between Cienfuegos and Santiago de Cuba, rests perhaps on a deeper bottom than any cable yet submerged. Portions of a cable laid between Santa Cruz and Porto Rico, recovered from a depth of 1,400 fathoms, were electrically and mechanically as perfect as when first laid. So that the suitability of this core for deep-sea telegraphy is amply established.

The mean temperature of the Cuba cable, as determined from its copper resistance tests, is about 34° Fah. Its insulation resistance, after one minute's contact with the battery, was about 5,000 megohms per nautical mile, which rose after thirty minutes' electrification to nearly 80,000 megohms per mile. This is the highest resistance recorded of any cable yet laid.

No cables containing this core have been abandoned, and portions of cable which have been picked up in the tropics and in the Persian Gulf, after some years' submergence, point to its suitability for warm climates.

4. *Warren's Core.*—Another form of insulated wire has been lately introduced by Mr. Warren, formerly electrician to Hooper's Telegraph Works, which, so far as we have seen, is likely to be useful in many cases. It stands exposure to high temperatures without injury, and does not deteriorate with exposure to air.

The india-rubber is applied in the same way as with Hooper's wire, and when consolidated is submitted to the action of chlorine in water, which gives to the core all the characteristics of vulcanised india-rubber, and over which it possesses many advantages, the most important being its non-liability to deterioration from

exposure to air and water, conditions which are seriously prejudicial to all forms of vulcanised wire.

The consolidation is effected by dry instead of steam heating, in a closed chamber or heater, which is kept at a temperature of 220° Fah. to 240° Fah. for two hours. Vulcanisation in this case not being required, the heating required is that at which the india-rubber softens and conglomerates.

The inner surface of the rubber is prevented from decaying or becoming *treacly* or soft by a mixture or compound containing a small proportion of iodine or bromine, which is applied over the conductor.

The insulation of these wires is about 1,000 megohms per nautical mile, and the inductive capacity is considerably lower than Hooper's wires or Smith's gutta-percha.

The specific gravity of the material is about 1·20. A length of this wire, which had been exposed to the full glare of the sun during the summer months, was found to have its electrical qualities perfectly unimpaired.

The jointing of this insulator is so readily performed that a joint perfectly sound and durable may be made in the smaller sizes in about five minutes.

Some lengths of this wire, which had been kept alternately wet and dry for nearly twelve months on board ship in the tropics, were found on their being tested to be perfect in all respects, and, as these wires had been made for four years, it forms an important proof of their durability.

For torpedo work, and other purposes of military engineering, this wire is eminently adapted.

5. *Wray's Compound.*—This is a mixture of shell-lac, india-rubber, and powdered silica and alumina, with about one-ninth of gutta-percha. From its admirable insulating properties, its low inductivity, its toughness, strength, and elasticity, and its not being softened by any climatic temperature, Mr. Latimer Clark placed it at the head of all materials known for the insulation of long submarine cables, nor has any drawback to its use as yet been discovered. For the insulation of cables, a combination of two or three materials offers advantages which no one material can ensure alone. The first layer next the copper conductor should be a thin strip of pure cut para-rubber, then layers of masticated rubber, applied by Silver's process, then a covering of gutta-percha, or, perhaps better, of Wray's compound; or the first layers might be of Wray's compound, and the outer coating of gutta-percha. By either of these plans, the benefits are obtained of the high insulating properties and low specific inductivity of caoutchouc and its compounds; and

from the perfection of the insulation, the most minute defect of manufacture would be readily detected.

Each successive layer of insulator on the cable has less influence than the preceding. By doubling the thickness of the coating, we do not double its insulation, or, in other words, halve the leakage. No thickness will altogether prevent conduction; and whatever quantity of gutta-percha may be put on, the cable can never be made a perfect insulator.

Let S be the exterior surface of the cable; s the area of the interior surface of the insulator in contact with the conducting wire; t the thickness of the coating; the conduction will vary as the mean sectional area of the outer and inner surfaces divided by the thickness

$$\frac{\frac{S+s}{2}}{t}$$

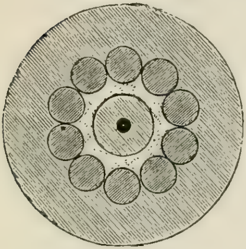
(274) Insulators have their conductivity *increased* by heat, whereas metals have their conductivity *impaired* by heat; both properties are obviously against telegraphy in hot climates. In gutta-percha the increase of conductibility and consequent leakage of the cable is seriously great in tropical climates; but the insulation is greatly increased, that is, the conductivity is greatly diminished, by pressure, though the improvement ceases when the pressure is removed. The conductivity or leakage of a gutta-percha cable is *diminished* if a *positive* current be applied for some time; but it is *increased* by the continual action of a *negative* current. To this fact no satisfactory explanation has been given.

All the submarine cables now in work are insulated either with gutta-percha or Hooper's core.

(275) **The External Protection.**—The insulated core is generally covered with strands of hemp or jute, laid or spread round it, to serve as a pad or protection against pressure from the iron wires afterwards applied. This covering is called 'the serving' of the cable. When several insulated wires to transmit distinct simultaneous messages are included in one cable, they are laid in a long strand with hemp between them to form a circular core; this hemp is called the 'worming.' The hemp is usually tanned to preserve it from decay; and it is somtimes laid on wet to facilitate the detection of any accidental injury to the gutta-percha. Unfortunately, both hemp and jute decay rapidly in water, and when exposed are apt to be eaten away by marine animals, some kinds of which have been found in the Mediterranean in depths of 1,200 to 1,600 fathoms.

The served core is commonly protected by iron wires, laid round and round in long helices, and abutting one against another, so as to present the appearance of an iron-wire rope. In the early cables the iron wire was generally galvanised, and its durability was thereby increased to a moderate extent; but iron is by no means a durable material, even when galvanised, and when the cable lies upon rocks exposed to the constant flow of water, or where the mud or sand contains peculiar constituents destructive to iron, a few months of submersion have been known to destroy the metal completely. To avoid this corrosion, the iron is usually coated with hemp, and this again covered with tar or some other protecting material. The silicated bituminous compound patented by Mr. Latimer Clark, applied over the wires, affords the best protection known. The Persian Gulf cable is coated with it from end to end, as is likewise the Isle of Man cable (Fig. 419), which is composed of a single conducting wire. To ensure permanency, cables in shallow seas are now laid weighing as much as 15 tons per mile, with shore ends weighing over 20 tons, to resist anchors. It has been proposed by Siemens to apply a covering of hemp outside the iron wire, and to wrap this round again with zinc armour.

Fig. 419.



Isle of Man Cable.

To avoid the occurrence of a permanent twist in uncoiling a cable, it should be taken out of the tank or off the drum in the same manner as it is put in or on; the opposite course will always put a permanent twist into a cable, and this twist concentrated at one point produces *a kink*, or tight-drawn loop.

A cable covered with good iron should bear a strain equal to 2 tons per pound of iron wire per fathom. Thus a cable with 3,750 lbs. of iron per knot, or 3·75 lbs. per fathom, in the sheathing, should bear $7\frac{1}{2}$ tons.

(276) **Types of Submarine Cables.**—The variations in the type of submarine cables differ but little from those just described. In shallow waters the usual form is a cable with stout galvanised iron wires covered with hemp and asphalted compound, the ends near the shore being armoured with heavier wire. In deep waters the cable varies according to the depths to be crossed. A deep-sea cable would consist of shore end, two intermediate forms as the water deepened, then the *deep-sea*. This form varies from a covering of a number of small homogeneous iron wires galvanised,

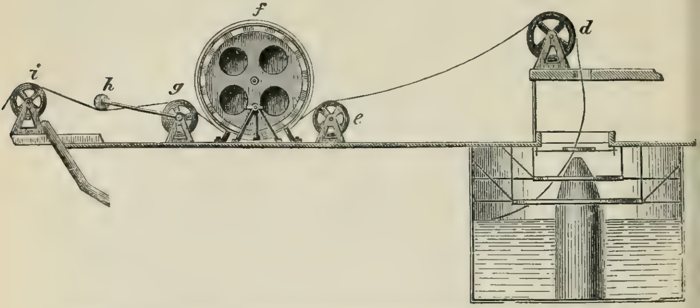
to the compound hemp and steel pattern of the 1865 Atlantic. This form has had added to it a light 'whipping' of yarn in the opposite direction, which prevents any broken wire springing up. The two later cables across the Atlantic have been made on this plan. A further alteration has been made by using a covering consisting of strands of hemp, alternating with strands of hemp and steel. In all these forms the cable is protected by being passed through a bath of hot compound. In the heavy cable between Holyhead and Dublin a slight variation was made in protecting the iron wires. Each iron wire was passed through a bath of compound and then served with a strip of canvas or tape soaked in a preservative mixture, the object being to give extra protection to the iron sheathing.

(277) **Submersion of Submarine Cables.**—For many years it was not deemed advisable to keep the cable covered with water, but after the numerous faults found in the Atlantic cable of 1857, and the peculiar heating of the Malta-Alexandria cable, it was considered absolutely necessary that from the moment of manufacture the cable should be kept continuously immersed in water, not only on shore but on board ship. All vessels now engaged in submerging cables are fitted with strongly-built tanks of a circular form, into which the cable is coiled and water admitted as required: in paying out the cable the water has to be pumped out. Formerly, when the speed of paying out was slight, the cable used to pass through the hands of the men from the coil to the guiding arrangement on deck, thence to the paying-out machine, which consisted of a large drum, round which the cable was coiled. The drum had around it a circular break-strap to check the speed of revolution and prevent the cable issuing too fast. As the depth of water encountered increased, and the speed of paying out also, new and improved arrangements were adopted. Amongst these none have contributed so much to the success of submarine telegraphy as the adoption of the 'cone and rings,' the invention of Mr. R. S. Newall.

Fig. 420 gives a general view of the paying-out arrangement. In the centre of the tank is a cone, round which is coiled the cable layer upon layer; above are fixed a series of rings of decreasing diameter. These rings are gradually lowered as the cable is paid out; they guide the cable and prevent it flying out by centrifugal force and going into kinks. As the cable rushes out it passes through the rings and continually rubs against the cone; it then passes over the v-wheel *d*, placed immediately over the cone and sufficiently high from it to allow the 'turn' or 'twist' to come out of the cable which had been put in in coiling. It then passes

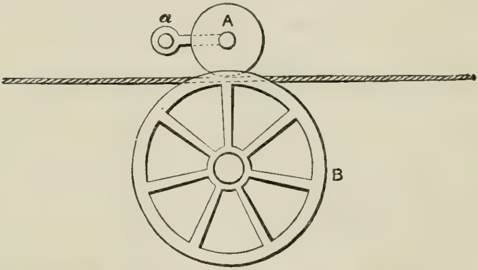
over several jockey-wheels (not shown, but like that in Fig. 421) to the guide-wheel *e*, passes several times round the drum *f*, over the V-wheel *g*, under the jockey *h* of a dynamometer, and finally over the stern-sheave *i* into the sea. On the drum *f* is placed an indicator

Fig. 420



to show the number of revolutions and the mileage of cable paid out. The jockey-pulley is used not only to keep the cable tight in front of the drum, but also to put some resisting strain on the cable. Fig. 421 gives a representation of one form of jockey-pulley. B is

Fig. 421.



a deeply indented V-sheave, in the groove of which the cable passes; the jockey-pulley A, centred at *á*, rests upon the cable and presses it deeper into the groove. The weight of the pulley can be increased by lengthening the arm and placing a weight at its end. The pulley B has usually a break-wheel strap attached to it, so that it can be reduced to a speed less than that of the outgoing cable.

(278) **Testing Submarine Cables during Submersion.**— In paying out the early cables the testing arrangements were of

the simplest character; a staff of operators and electricians was employed on board the ship, and a staff of operators on shore. Arrangements were made for speaking and for testing; the latter of which was usually carried out on board the ship alone, and consisted of the operator on shore insulating the cable, putting it to earth, and sending currents at certain stated intervals. In order to avoid the constant attendance of a clerk during the frequent repairs of the Hague cables, a clock was arranged to perform these offices mechanically, and it was with the utmost regularity that the cable was insulated and put to earth, and a current sent at the required intervals. A very much improved form of clock was used with great success in paying out the last Persian Gulf cable (1869). As the manufacture of gutta-percha improved, and its insulation became gradually higher and higher, more elaborate and perfect systems were required for testing during manufacture and during submersion, and the high state of insulation of all our cables now is due to the rigid nature of the tests, a result greatly attributable to the use of the Thomson reflecting galvanometer (145) and of the marine galvanometer (146). The greatest improvement in testing during submersion is due to Mr. Willoughby Smith, whose plan has now been used for some years in paying out the long submarine cables. In this plan no alteration is made in the connections; the cable end at the testing house at the landing end is permanently connected to an electrical table of instruments (used for various purposes) and through a *very high* resistance to earth, so that if a permanent current be kept on a slight and constant deflection is observed on the galvanometers on board ship and on shore during the whole process of paying out. Signals can be transmitted by slightly increasing or decreasing the deflection, which is done by altering the potential of the battery. The usual tests for insulation and for conductivity are carried out with ease and with regularity, the use of sliding resistances facilitating the operations greatly, as results can be read off at once.

(279) **Accidents to Submarine Cables.**—The most frequent source of accident to a submarine cable is that of 'anchors;' so many of our cables cross anchorage grounds, and vessels may be found anchoring almost anywhere. It is for this special reason that the cables near the shore, and where vessels may be expected to anchor, are made of the strongest type, but even then they are liable to accident from the same cause. Rocky bottoms are, again, another cause, and it is merely a question of time when the cable resting on a rock will be chafed through, the constant action of the tide producing the necessary motion to cause friction against the rock. A mass of sea-weed has been known to carry a cable away, and

great damage has been done where cables have crossed mineral beds. But, in addition to these, there are various causes of damage to a cable which are of a serious nature.

The first appearance of any damage done by animal life to a submarine cable appeared in the Levant cable, laid by Mr. Newall, who speaks of the destruction of the hemp by a species of 'teredo.' Mr. Siemens speaks to the same effect, and says, 'This cable, which was laid in 1858, and taken up again last summer (1859), was found to be beset by another enemy in the shape of millions of small shell-fish or snails, accompanied by small worms, which had completely destroyed the unsheathed hemp, and eaten some circular holes in the gutta-percha.' Professor Huxley wrote as the result of his examination of these shells, 'The specimens you have sent me remove all doubt as to the nature of the mischief-maker in the cable. It is a bivalve shell-fish, the xylophaga, closely allied to the ship-worm (teredo), but distinguished from it, among other peculiarities, by not lining its burrow with shelly matter. The xylophaga turns beautifully cylindrical burrows, always against the grain, in wood; and I have no doubt it perforated the hempen coating of the cable in the same way. On meeting the gutta-percha it seemed not to have liked it, and to have turned aside, thus giving rise to the elongated grooves which we see. Nothing is known, so far as I am aware, of the range in depth of xylophaga, so that I cannot answer your enquiry as to whether it is probable that cables immersed in 600 to 2,000 fathoms of water would be attacked or not.'

In 1860 several portions of cable covered with hemp and steel wire were picked up in the Mediterranean, off Minorca, which were found in places, and up to deep water, very much attacked by xylophaga, the hemp between the steel wires being eaten away into holes with the regularity and spacing of those in a cribbage-board. As in previous cases, the gutta-percha was penetrated to various depths, but not more than the size of the shell-fish. It was generally considered that the xylophaga did not penetrate, owing to its dislike to, gutta-percha; but some persons, at the time, thought there was a great deal of doubt about the point, for there was no sign amongst the great length of cable so damaged of any dislike, the main sign being that there had been *no time* for further penetration.

That the xylophaga does penetrate gutta-percha to an injurious extent was found to be the case with some experimental wire laid in Kurrachee harbour; this core was subsequently found to be pierced in numerous places, to such an extent as to destroy the insulation. No such severe case has elsewhere been met with,

although xylophaga are now found in almost every sea where cables have been laid.

It may be generally assumed that a core with a solid sheathing of iron wire, so long as that sheathing remains, is safe against the attacks of these destroyers, but that a core cannot be considered safe so soon as an opening presents itself, for, up to the present time, it is impossible to say where they do not exist. In the operations connected with the attempt to repair the 1865 Atlantic cable, a portion of the 1858, or original cable, was brought to the surface. Where the wire sheathing had disappeared it was found that the gutta-percha had been attacked; 'for where the core has been bared there are distinct marks of worms, such as one sees in very old hard timber, or in the rich calf binding of old folios in a library.'

Several cases have occurred at different times of cables being damaged by the attack of inhabitants of the sea. The Cuba and Florida cable was once damaged by the bite of some large fish, and a similar accident happened to the China cable. In the Malta-Alexandria cable a piece of core, from which the sheathing had been worn, was found to be penetrated by being bitten by a shark, pieces of the teeth being left in the gutta-percha, indicating unquestionably the cause.

Some details of a fault which happened some time since to the Singapore cable are interesting. This cable was laid in December 1870, and the first stoppage occurred in the following March, and was found to be 200 miles from Singapore. The cable was pierced, and pieces of bone were found crushed in the middle of the hole. This specimen was examined for a long time by Mr. Frank Buckland, and it was remarked that the damaged place was caused by piercing, and not by being bitten by the force of a jaw. He accidentally found in his collection a saw-fish, from which he detached the saw, and found that he could make in the cable an incision similar to that which already existed. Mr. Buckland stated that the saw-fish have the habit of penetrating the bottom of the sea in search of food, and giving a backward and forward motion to the species of lance with which they are armed. The extremity of the saw of one of these fishes would become entangled in the exterior wires of the cable; a further brisk movement of the fish would make it penetrate; and, finally, violent struggles would break the saw, after having pierced the cable through and through, as seen in the damaged piece.

A curious fault occurred in the Persian Gulf cable.

'The soundings at the fault were very irregular, with overfalls from 30 to 70 fathoms. On winding in the cable unusual resist-

ance was experienced, as if it were foul of rocks, but, after persevering for some time, the body of an immense whale, entangled in the cable, was brought to the surface, where it was found to be firmly secured by two and a half turns of the cable immediately above the tail. Sharks and other fish had partially eaten the body, which was rapidly decomposing, the jaws falling away on reaching the surface. The tail, which measured fully 12 feet across, was perfect, and covered with barnacles at the extremities.

'Apparently the whale was, at the time of entanglement, using the cable to free itself from parasites, such as barnacles, which annoy them very much, and the cable hanging in a deep loop over a submarine precipice, he probably, with a fillip of his tail, twisted it round him, and then came to an untimely end.'

This is, without exception, the most extraordinary accident that has happened to any submarine cable that has come within our knowledge, although many strange accidents have arisen. In one case the cable across the river Yar, in the Isle of Wight, was broken by a bullock, which, falling overboard, got entangled in the cable, finally breaking it.

The causes of interruption we have alluded to are impossible to provide against, with the exception of the attacks from xylophaga, and it is to be trusted that they will always continue to be of very rare occurrence. The use of silica in the compound now generally applied outside all cables is hoped to be a preventive against the insidious attacks of the persevering shell-fish. The following observations were made in the Persian Gulf at Kurrachee, where some experimental cables were deposited in water known to be inhabited by 'borers.' The specimens were lengths of about 200 yards of gutta-percha and india-rubber cables and plain core:—'On recovery, after a submersion of nearly ten months, the only piece which tested good was the length of india-rubber cable; the remainder were injured by "borers" and by barnacles. Bare india-rubber core is more susceptible of injury from barnacles than bare gutta-percha. As the barnacle grows, the base of the shell cuts into the yielding rubber; a second shell attaches itself to the side of the first; the growth of the circumference proceeds towards the conductor, and eventually the sharp edge of one of the cluster reaches the copper wire.' The experience seemed to show that although the 'borer' did attack the india-rubber, it was in a much less degree than when it attacked gutta-percha.

Another species of 'borer' seems to exist very largely, and is to be met with about the English, French, and Norwegian coasts as well as in the Atlantic. During some repairs to the Dublin-

Holyhead cable it was noticed that at about six miles from Port Crugmor (the landing-place) at every broken wire and open place in the sheath all the inner hemp serving was completely eaten away by worms, leaving the percha core exposed, which in one or two places was scored from the same cause. At other points the gutta-percha was found pierced directly inwards, and a small worm found in each hole. At the same spot the hemp was eaten away, and two or three different varieties of worms were noticed. These varieties were recognised by Dr. Carpenter, F.R.S., as *Lepidonotus equamatus*, *Evarne imfar*, and *Nereis pelagica*, all well-known English forms. The small worm which attacked the gutta-percha was recognised as a small crustacean, the *Limnoria lignorum* of Rathké, known to British naturalists as the *Limnoria terebrans*. The Limnoria is about one-sixth of an inch long; the head is furnished with at least five pairs of claws and other appendages, and legs resembling those of the lobster are attached to the six first rings and the last ring of the body.[1]

Numerous faults were found on the Brazilian coast, caused by the saw-fish. In a length of thirty miles no less than six faults were discovered of this nature; in each case fragments of a bony nature (portions of the saw) were found in the faults.

(280) **The Electrical Properties of the Submarine Cable.**—It has been shown in a previous chapter (chap. xv. § 171) that when an insulated conductor is brought into the neighbourhood of a conductor that is insulated the latter acquires an increased electrical capacity, in consequence of the reciprocal inductive actions of the two conductors; that the nearer the two conductors are brought towards each other, the greater will be the amount of that inductive influence, and that different non-conducting bodies or *dielectrics* have each a natural power belonging to itself, which is called its 'specific inductive capacity' (10). As induction diminishes rapidly as the distance increases, its operation in the case of a telegraph wire suspended and insulated on poles is small, but that even here an influence is exerted on the neighbouring wire and the earth, is proved by the sensible time that is required to transmit signals through very long wires. On half a mile of suspended wire, for example, 500 or 600 signals may be readily sent per minute, but at a distance of 500 miles the current would appear continuous.

When one pole of a battery is connected with one end of an insulated telegraph wire, and the other pole with the earth, a current flows into the wire until it has attained the same poten-

[1] *Journal of the Society of Telegraph Engineers*, vol. iv. p. 363.

tial as the battery. If the wire be short, the small static charge which it has acquired is immediately lost by dissipation on breaking contact with the battery; but if it be long, the charge lingers in the wire, and thus causes the signals to run together, so that it becomes necessary to clear the wire by sending a reverse current into it. The nearer the wire is to the ground, the greater of course is the amount of inductive action set up between the wire and the earth, and the greater therefore the electrical *clogging* of the wire; and when the wire is covered with an insulating material, and buried, it becomes an enormous Leyden jar, having for its inner coating the wire, and for its outer coating the earth. Every mile of such wire (No. 16) presents a surface of 85·95 square feet, and the inductive circumstances being assumed to be the same, receives the same charge from a source of the same tension as a Leyden jar having an equal number of square feet of tinfoil coating. There is, however, this material difference between the two cases: though both are discharged in a time inappreciably minute to the senses, the discharge from the wire occupies a comparatively much longer interval than that from the coatings of the jar. This discharge current affects in a very serious manner the speed with which signals can be transmitted through the wire.

This peculiar character of insulated and buried or submerged wires was not suspected when underground telegraph wires were first employed, for in the usual practice a voltaic current does not communicate a statically intense charge of electricity to a Leyden jar. It was first made evident by the extraordinary retardation which the electrical current experienced when it had to pass through subterranean or submarine channels in the course of its journey. In the early experiments made to determine the velocity of electricity through metallic wires hundreds of thousands of miles appeared to be traversed in a second, whereas in similar experiments made on the underground lines formerly running between London, Manchester, and Liverpool, it seemed that scarcely thousands of miles were passed in the same period. Indeed, according to Edward Bright (*British Association Report*, 1854), the velocity of currents in ordinary use for telegraphic purposes in submarine conductors does not exceed 1,000 miles per second.

(281) **The Retardation of Signals.**—These effects of induction, as they had been observed by him in the subterranean lines of Prussia, were first described by M. Werner Siemens in 1850. These effects were the reception of charge and its retention after the cessation of contact with the battery. The retardation of the current was first witnessed by Latimer Clark on March 20, 1852. It is this retardation which forms the great difficulty in modern telegraphy.

'There is no phenomenon in electricity,' observes Clark (*Report of Submarine Telegraph Committee*), 'that has a more important bearing on the electric telegraph than that of induction, and none which interferes more with the commercial success of telegraphic enterprise. If it were not for this evil presenting itself in the form known as retardation of the current, any telegraph cable, however long, could be worked at almost any speed; and although much may be done to reduce its effects, there is at present no known method of avoiding them altogether.'

On the occasion on which the phenomenon of retardation was first observed, an attempt was made to work an electro-magnet and a Bain's printing apparatus through 100 miles of wire immersed in a canal, and 175 miles of wire stored up dry in a manufactory. In so doing it was found that there was no difficulty in working even with very small battery power through the whole length; but it was instantly noticed that the current took a very perceptible time in travelling the 100 miles. The experiment was varied in several ways, both with the electro-magnet and with the printing apparatus, but the result was uniform, that even when the current had to travel through the whole length of the wire before acting on the magnet retardation was perceived. In one experiment the battery and the electro-magnet were placed at one end of the wire, and the contacts were made and broken at the other; but although the battery and the magnet were close together, the same retardation was perceived. It was noticed also that the marks made on the printing paper by the current were not only slow in appearing, but often on their appearance, instead of ending abruptly and instantaneously, as they do in overground lines, the mark *tailed off gradually to a point*. The cause of the phenomenon was at once perceived to be *induction*; and to verify it, the 100 miles in water were detached, and the 175 miles on dry land used alone, and, as was to be expected, no retardation whatever was perceptible.

The retention of charge by subterranean or submarine cables is also well shown by the following experiment described by Mr. Whitehouse (*Atlantic Telegraph*, p. 10):—

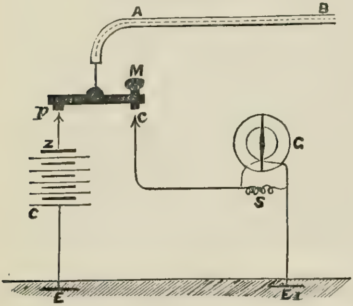
Fifteen miles of insulated wire, with a conducting layer external to its insulating investment, were arranged with one end turned up into the air; the same was done with 200 miles of the same wire. To both of these lengths was communicated as full a charge as it had the capacity to retain. Each wire was then discharged through a fine wire coiled round a bar of soft iron, so that the bar was rendered a magnet *pro tempore*, i.e. during the actual current of electricity. Upon measuring the force of each discharge current, estimating it by the number of grains the temporary magnet was capable of lifting, it was found that in the case of the 15-mile length the weight lifted amounted to 1,075 grains, and in that of the 200-mile length to 2,300 grains. A current which lifted 18,000 grains by simply running through the appa-

ratus thus arranged, upon being sent into a coated insulated wire 498 miles long, lifted 60,000 grains when allowed to flow back as discharge, and even 96,000 grains if the discharge passed from both ends of the wire at once, and round the same temporary magnet.

Submarine and subterranean insulated wires do not, therefore, act simply as conductors, or as mere channels through which the electrical current flows, but as *reservoirs* storing up electricity in quantities proportional to the length of the wires. A sensitive magnetic needle placed by the side of a long and completely insulated wire, when it is charged, gives clear indications of the first *rush* of electricity into the wire, of the retention of the charge for several minutes after the charging contact has been broken, and of the final *rush* out or discharge of the electricity in the opposite direction when the wire is connected with the earth by its nearer end. These phenomena were assigned to their true cause by Faraday (29, Ex. 10, p. 53).

By means of the arrangement shown in Fig. 422, the discharge from a yard of insulated cable may be made evident on a sensitive galvanometer if charged by a large voltaic battery—say, 100 Daniell cells (*Fleeming Jenkin*). M is a common Morse key by which the conductor of the cable, A B, can be placed in connection with the battery Z C, by a contact at *p*, and then removed from the battery and immediately connected at *c* with one terminal of the galvanometer G, the other terminal of which is in connection with the earth at E. The contact at *p* charges the cable, and that at *c* discharges it through the galvanometer. As the quantity of electricity which goes into the cable must be equal to that which leaves it, if the galvanometer G were placed between Z and *p*, it would be affected to the same extent by the entrance of the charge as by its exit at *c*, but in the reverse direction.

Fig. 422.



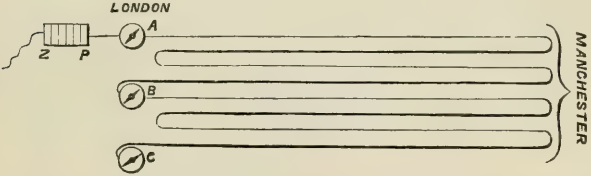
The following experiments were made in October 1853, by Mr. Latimer Clark, in the presence of Professors Faraday and Airy :—

1. One hundred miles of gutta-percha wire were immersed in a canal, the distant end of the wire being permanently disconnected with the earth.

The near end was also disconnected, but had a galvanometer attached, which indicated any current which passed into or out of the wire. The battery was arranged with one pole permanently connected with the earth. The other pole of the battery was now brought into contact with the line wire. The galvanometer was immediately and very violently deflected to the right by a current passing into the wire, but this current ceased almost immediately, the needle resumed its nearly vertical position, and remained quiescent. The connection with the battery was now broken, and the galvanometer, having no current passing, became perfectly vertical. Things being in this position—that is to say, both ends being disconnected from the battery—the near end was connected with the earth; the galvanometer was now deflected in the opposite direction by a returning charge quite as violently as in the first instance, proving that a charge had been retained in the wire. No such phenomena were observed when the 100 miles of cable, instead of being submerged, were lying in coils in a dry store-room.

2. The length of wire in circuit was 1,490 miles, of which 70 miles were on dry boards, the remainder being in iron or earthenware pipes, buried underground along the railway between London and Manchester. The gutta-percha was a quarter of an inch in diameter, and the interior copper wire one-sixteenth of an inch; each wire was lapped round with cotton tape dipped in coal tar, and then dusted with fine sand. One hundred miles of the copper wire presented 8,250 feet of surface. The wires were loosely bound into a bundle of eight wires by twine, and drawn into the pipes, thus forming eight independent circuits from London to Manchester, which were all joined up into one circuit of 1,490 miles. The battery power used was 508 cells of Daniell's battery. All the eight wires were joined up into one

Fig. 423.

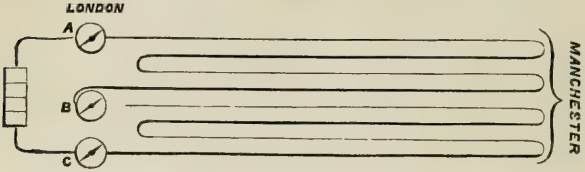


continuous length, viz. the zinc pole of the battery to the earth, the copper pole through a galvanometer to the line wires, thence to Manchester and back twice, and through a second galvanometer, again to Manchester and back twice, and through a third galvanometer, and then to earth. On making contact with the battery, the needle of the *first* galvanometer was deflected with great violence for an instant, and immediately afterwards settled at an angle of nearly 90°. After the lapse of a full *second* or more the needle of the *second* galvanometer was deflected in the same direction, not with such violence, as in the case of the first, but rather slowly and tardily, settling to an angle of about 40° or 50°. Again, after a *still longer* interval, the current appeared to reach the *third* galvanometer, the needle deflecting feebly with a slow movement, but increasing gradually, apparently by jerks or pulsations, till it remained at an angle of 15° or 20°. On disconnecting, the first galvanometer fell back first, the second and third last.

3. In this experiment there was no earth connection used, the poles of the

battery being connected directly to the exterior galvanometer A and C, forming a closed circuit. On making connection with the battery, both the exterior galvanometers A and C were violently deflected in a parallel direction by a charge of positive and negative electricity evidently passing into the respective wires, the needles afterwards continuing deflected strongly in

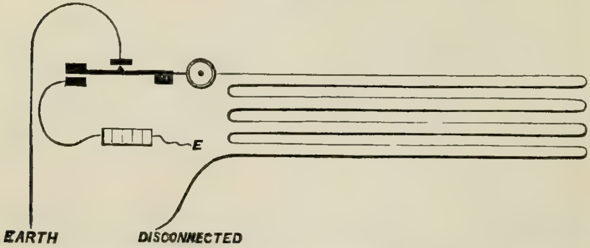
Fig. 424.



the same direction. The intermediate needle B was not deflected until after an interval of a full second or more, when it settled quietly in the same direction without any jerk. When the battery connection was broken, and the galvanometers A and C connected together, a powerful discharge returned through each of them, deflecting them in a reverse direction to that caused by its entrance.

4. One pole of the battery was put to earth permanently; the other pole was put into contact with one end of the wires (all joined on to each other =1,490 miles) by a finger-key which, when pressed down, put the line wires into contact with the battery, the current passing through the galvano-

Fig. 425.



meter into the line wire. When the spring returned up, the battery connection was broken, but at the same time a contact was made with the earth, and the induced current returned out of the line wire through the galvanometer and the key to earth.

On depressing the finger-key, a powerful charge passed through the galvanometer, and the needle was deflected violently in one direction; on raising the key, the return current deflected the needle still more powerfully in the opposite direction, at the same time completely reversing its poles. This was repeated many times. The return charge, or inductive discharge, was also taken after intervals of four or five seconds.

In the Gutta-percha Company's works, this return current was

in one case very evident after a lapse of *five minutes*, during which time the wire (100 miles) had been totally disconnected from the battery.

When a current was sent along 500 miles of naked iron wire suspended in the air, it appeared at the distant end almost instantaneously, and ceased to flow almost at the same time that it was stopped at the near end.

In an experiment with 800 miles of subterranean wire, the battery power was varied from 31 to 516 cells; the time occupied before the first appearance of the induced current was about half a second, and it was sensibly the same for all the electromotive forces tried.

(282) **Measurement of the Currents produced during the Charging and Discharging of Wires.**—The first method of measuring the amount of induction in telegraph wires, and the one ultimately adopted, was by measuring the swing of the needle of a vertical galvanometer. The currents are of such short duration that they cannot affect the needle in a permanent manner; the forces which produce the deflections are, as in the similar case of a balistic pendulum, generally assumed to be as the *chord of the arc* through which the needle passes. The arcs themselves, when they do not surpass 30° or 40°, may, for these experiments which do not admit of the greatest accuracy, be considered as a sufficient approximation (*Wheatstone*). In general, it was found by Mr. Latimer Clark that, when the galvanometer was suspended by a single fibre and small arcs of vibration recorded, the number of degrees of swing, or the arc of vibration, was nearly proportional to the amount of induction; but there were considerable variations in different instruments. In the galvanometer employed by him in all his experiments, the oscillations up to at least 70° were strictly proportional to the amount of induction.

The amount of charge—that is, the quantity of electricity stored up by induction—is directly as the electromotive force of the battery, as shown by observations taken with batteries varying from 1 cell to 508. If the deflection given by a known mile of telegraph wire, with a known number of cells, be noted, and if we take another mile of different wire, and vary the number of cells until it gives the same deflection on the same instrument, the relative amount of induction in the two cables will be inversely as the number of cells.

With a wire of ordinary dimensions the amount of charge or of induction I may be taken as varying *inversely* as *the square root of the thickness* of the coating of gutta-percha t, and also

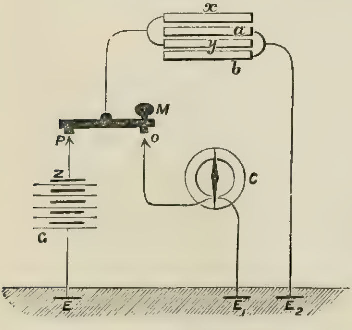
directly as *the square root of the diameter* of the copper conducting wire d, or

$$I = \sqrt{\frac{d}{t}}.$$

From this law, it follows that, if we increase the diameter of the conductor and the thickness of the dielectric in the same proportions, the induction will remain constant. Also it appears that the law of variation with different thicknesses of gutta-percha is different from that in air, where the quantity of electricity accumulated under induction between two opposing surfaces varies inversely as the thickness of the plate of air intervening, and not as the square root of the thickness.

For measuring the charges in submarine cables, Siemens employed an instrument in which a reversing key, driven by an eccentric wheel, gave a rapid succession of charges into the cable. These short impulses, in passing through a galvanometer, caused a permanent and nearly steady deflection of the needle, which could be read with great accuracy. Wheatstone modified this machine by driving the eccentric by a multiplying wheel, and thereby made its indications surprisingly delicate. When driven rapidly, with a battery of 500 cells, it readily exhibited on a galvanometer the succession of discharges from 12 inches of wire, one-sixteenth of an inch in diameter, suspended in an apartment. Mr. Latimer Clark adopted this system of rapid motion to a differential instrument with three reversing keys. With this apparatus, which he calls a *differential inductometer*, using a battery of 500 cells, and a galvanometer with 30,500 convolutions of wire, the extra immersion of half an inch of telegraph wire, or even the approach of the hand, could be rendered readily perceptible.

Fig. 426.



Professor Fleeming Jenkin adopted this plan:—First make a standard knot of cable, Leyden jar, or condenser; take the discharge from that with the arrangement shown in Fig. 426, where a b represent the plates of a condenser in connection with the earth, and x y insulated plates separated from them by mica,

gutta-percha, paraffin, glass, or air; M the Morse key, by which the condenser $x\ y$ may be brought into connection with the battery Z C by a contact at P, and then removed from the battery and connected at O with the galvanometer. Next charge the cable from the same battery, and by trial bring the galvanometer to the same deflection by shunting part of the current through resistance coils, which can be adjusted. If one-hundredth part of the current pass through G, then the capacity of the cable is one hundred times that of the condenser. The relative charges, if not differing much, may be taken as proportional to the deflections on a reflecting galvanometer (145), or, more strictly, to the sines of half the angles on ordinary galvanometers. A galvanometer with a comparatively heavy needle is better for this purpose than a reflecting instrument with mirror and light magnets, owing to the effect of the resistance of the air. Other and more accurate methods of measuring the inductive capacities of cables are:—1. By the transfer of a charge from one condenser to another, and the measurement of the *potential* before and after the transfer; 2. By the relative effect of two discharges in opposite directions through a differential galvanometer (144); 3. By balancing a succession of discharges through one coil of a differential galvanometer against a permanent current adjusted with the aid of resistance coils (111); and 4. By balancing the discharges against a permanent current in an arrangement resembling a Wheatstone's balance (110).

Experiments were made by Mr. Clark to determine the comparative inductions of copper and iron conductors; and it was found to be sensibly the same as might be expected, from the well-known fact that electricity under induction dwells only on the surface of conductors, and that its quantity is the same whatever may be the material of which the conductor is composed. The same electrician also found that the amount of induction received from a cable was not altered by allowing the charge to pass through a second length of cable. A perfectly insulated cable, connected with a battery, will ultimately attain the same maximum of charge whatever be the length of the wire, or whatever be the resistance of the intervening conductor: thus, one mile of plain gutta-percha wire was charged with a battery power of 128 cells, a resistance equal to about 700 miles of line being interposed between the battery and the cable, so that the charge and discharge had to pass through this length of wire before reaching the cable; the amount of induction charge, as measured by the galvanometer, was 30·46; of discharge, 30·36. The same wire was now charged with the same battery, and connected direct to the galvanometer

without any resistance; the amount of induction-charge was 30·38, and of discharge, 30·66.

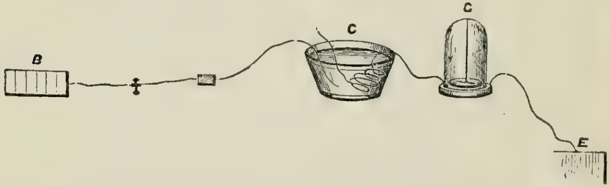
By the following interesting experiments, it was proved that the amount of current which enters the cable is exactly equivalent to that which leaves its exterior, and is of course of the same denomination:—

1. A large tub of water was carefully insulated by suspending it on slings of gutta-percha, and about half a mile of guttapercha-covered copper wire was placed in it. The battery power used was 256 cells. The negative pole was connected with the earth, and the induction was measured in the usual way, by the swing of the needle of a horizontal galvanometer; the *charge* amounted to 0·7, the discharge to 0·5, the leakage being 0·25. The charge here observed was obviously caused by the induction of the surrounding walls and ceiling of the room.

2. The water was now connected with the earth, and the observations repeated; the results were—*charge*, 28·36; *discharge*, 26·32; *leakage*, 1·72.

3. The connections were now changed in the manner shown in Fig. 427; the current from the battery, instead of being sent into the wire, was sent

Fig. 427.



into the water in the tub, the wire being connected through the galvanometer with the earth; the observations were repeated; the results were—*charge*, 27·92; *discharge*, 25·92; *leakage*, 1·95.

4. The galvanometer was now removed from the coil of wire and placed in circuit with the wire leading to the earth, so as to measure the amount of electricity passing from the tub to the earth. The battery was connected directly with the wire: the results were—*charge*, 28·12; *discharge*, 25·88; *leakage*, 1·87.

5. The galvanometer was placed between the wire proceeding from the battery and the wire dipping into the water of the tub, but not in direct contact with the coil, so as to measure the amount of electricity passing from the battery into the water. The cable was connected with the earth. The results were—*charge*, 28·72; *discharge*, 26·1; *leakage*, 2·42.

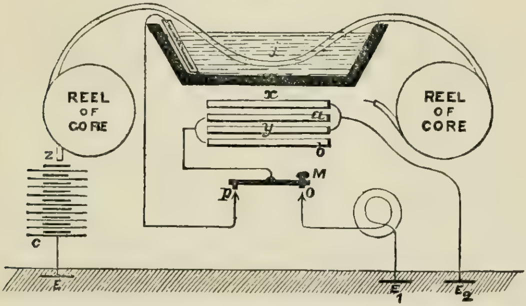
The results were the same with negative as with positive electricity, and it was further proved that with the same electromotive force the cable gives the same induction, whatever be the source from which the electricity is derived.

The induction discharge may be used to measure insulation

thus (*F. Jenkin*):—Charge the cable by contact at p (Fig. 422), and then break contact at p without making contact at o. The charge, which is as it were bottled up inside the cable, leaks gradually through the gutta-percha. After, say, one minute, make contact at o, and observe the difference between the deflection thus obtained and that obtained when the cable is discharged immediately after being charged. The difference measures the loss in one minute (*vide* 286).

A similar test is applied by Mr. Latimer Clark to the testing of joints, a method which has been universally adopted. A joint j (Fig. 428) is placed in an insulated trough of water connected with

Fig. 428.



a condenser; the battery is applied to one end of the cable, and any slight leakage which may occur at the joint gradually accumulates in the condenser. After a minute or more the condenser is discharged through the galvanometer, which may then show the result of a minute's accumulation, even when the permanent current passing at any moment would not have been sensible.

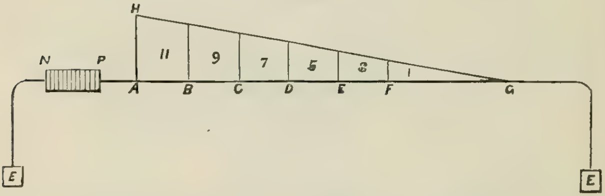
(283) **Electric Waves.**—If two or three successive currents of short duration be sent into a long cable, they will, if of sufficient magnitude, travel onwards *separately*, and emerge in succession from the other end; and this fact is usefully taken advantage of to increase the speed of working in long cables.

Electric waves may be of three kinds:—1. Those consisting of *positive* electricity; 2. Those consisting of *negative* electricity; 3. Those consisting of both positive and negative electricity together. In waves of positive electricity the potential of the wire rises alternately *above* that of the earth, and sinks to 0°. In negative waves the potential falls *below* that of the earth, and rises to 0°. They are identical in their characteristics, and follow the same

laws. In working with double currents—that is, with alternate negative and positive waves—there is an important practical advantage. It is necessary with single currents to use a spring, or other mechanical contrivance, to bring the magnet or the armature back to its position of rest. The force necessary to effect this has to be subtracted from the efficient force of the current. With double currents the armature or magnet moves passively under the influence of the alternate currents, the whole power of the current being effective to make and break contact.

(284) **The Amount of Induction is not the same at all Points of the Line.**—Let A, B, C, D, E, F, G represent a long sub-

Fig. 429.



marine cable with a current flowing through it, and let A H represent the potential near the battery; it is found, experimentally, that the potential at other points, B, C, D, &c., varies as the distance from the battery, and that the line H G represents the potential of the electricity at all points. But the quantity of induced electricity varies as the potential; therefore the perpendiculars, B, C, D, &c., will correctly represent the amount of induction at all points along the line.

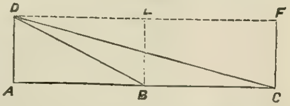
The whole amount of induction in the cable is represented by the triangle H A G; and if this triangle be divided into sections by the perpendicular lines A, B, C, D, E, F, the area included between any two of these perpendiculars will correctly represent the amount of induction upon that section of the cable. Now it is the property of a triangle, that if the base, A G, be divided by any number of equal lengths, and perpendiculars such as B, C, D, &c., be erected upon it, if the area of the smallest section, F G, = 1, the area of all the other sections will increase in the ratio of the odd numbers, 1, 3, 5, 7, 9, 11. Consequently, if the whole length of any submarine cable be conceived to be divided into any number of equal parts, the quantity of electricity stored up inductively in each section will be in the ratio of 1, 3, 5, 7, 9, 11, &c.; therefore, if a cable be divided into three parts, the section nearest the battery will have five parts of electricity, the middle three

parts, and the distant section one part; and this independent of the battery power, bearing in mind that the standard potential of any section depends not on the number of cells, but on the actual potential measured close to the battery.

If the battery be disconnected from the cable, the whole of the electricity will flow out at the distant end to the earth; but if the *near* end of the cable at the instant it is disconnected from the battery is connected with the earth, a much larger quantity of electricity rushes out at the near end than at the distant end, and the strength of the current is very much greater.

(285) **Laws which Regulate the Quantity of Charge which Enters a Cable.**—(*Latimer Clark.*)—The entire commercial value of the telegraph depends upon the time occupied in charging and discharging, and the rate at which signals can be distributed through the cable within a given period. Before the contact of the battery with a cable whose distant end is to earth, the potential of the former is at its maximum; but upon contact the current enters freely into the empty cable, the potential, unless the battery be immensely large, at first falling, and again rising as the successive sections of the cable (284) gradually become charged. The potential near the battery gradually becomes greater, until the flow of electricity out at the distant end equals the supply at the near end, and all the potentials have attained their final states. Now after the equilibrium has been obtained, we have seen (284) that the quantity of electricity in any given section of the cable, as A B, may be represented geometrically by the triangle A B D; also, that if the potential of the battery remain the same, the quantity in any longer cable, A C, may also be represented by the triangle A C D. Now if we suppose the cable A B to be 100 miles long, and A C 200 miles, we shall see that the whole amount of electricity under induction in A C will be twice as great as in A B; for the triangle A B D is one-half of the parallelogram A B E D, and the triangle A C D is likewise half the parallelogram A C E D; and since of these two parallelograms one is just twice as large as the other, the triangle A C D will be twice as large as A B D. The whole electricity in the 200 miles will, therefore, be exactly twice as great as that in 100. It will be seen, at the same time, that the average distance through which the electricity has to flow before reaching its destination, and before returning to the earth, is exactly twice the average distance which the electricity in A B has to flow; and, therefore,

Fig. 430.



the longer cable A C not only has twice the electricity in it, but that electricity has twice as far to travel, and consequently the time occupied by the charge and discharge will be *four* times as long. Similarly, if the cable A C had been three times as long as A B, the quantity of electricity under induction would have been three times as great, and the average distance it would have had to traverse would also have been three times as far, and consequently it would have taken *nine* times as long to become charged. In other words, the time occupied in charging and discharging a cable with its distant end to earth will, according to this theory, vary as the square of its length. This law was first enunciated by Sir William Thomson in a paper read before the Royal Society in May 1855, and published in the Proceedings of that year, in which the question was submitted to the highest mathematical analysis.

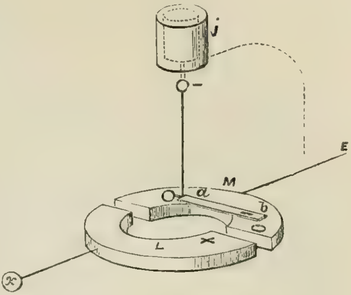
There is no increase in the speed of transmission of the electric current by increasing the battery; for, let the induction in a cable with any given electromotive force—say, 100 elements—be represented by a triangle, as in Fig. 430, and let the time occupied by the passage of the electricity into the cable be represented by 1. Now if we double the battery, the quantity of electricity contained in the cable will be twice as great as it was before; but while entering the cable, each particle will be forced in under twice the potential that existed in the first case; and we have seen that the quantity of electricity flowing through a wire in a given time varies directly as the potential; consequently the double quantity contained in the cable under the double potential, will occupy the same time in entering and leaving the cable as the original quantity did under the lower potential.

(286) **Testing Short Lengths of Cable.**—An instrument frequently employed for this purpose is Thomson's divided ring electrometer. A general description of this beautiful instrument has already been given (42); its application to the testing of cables will perhaps be more clearly understood from Fig. 431, which illustrates the principle on which it is constructed (*Fleeming Jenkin, Cantor Lectures*) :—

A light flat aluminium needle, *a b*, balanced by a counterpoise, is suspended by a platinum wire from a point connected with the interior coating of a Leyden jar. Under the needle two half rings, L and M, are placed, with the division on one side, directly under the aluminium needle in its position of rest. The whole is placed inside a metal case, not shown in the drawing. Suppose the needle *a b* not to be charged, then if L be connected with *x*, an electrified body, while M is connected with the earth, the needle will turn slightly towards L, and this will be the case whether the electricity of *x* be positive or negative. If we now charge the Leyden jar with, say negative

electricity, the needle will be brought to the same potential as the inner coating; it will be much more strongly attracted than before by L if the electricity of x be positive, and would be powerfully repelled if x were negative. If x loses its electricity and returns to the potential of the earth, the needle a b will return to its original indifferent position between L and M, being equally attracted by both. One object of connecting the needle with a Leyden jar is to provide a considerable supply of electricity for the needle, so that the unavoidable slight leakage which must occur may not affect one test, or even a series of tests. A loss of one unit of electricity per minute will matter little if the whole store be 1,000, such as may be held by the jar; but if the store be only one or two units, such as would be received by the needle, such a loss would be fatal. The deflections will also be greater, and the instrument will be more sensitive, the higher the potential with which the jar is charged; but the indications will only be constant so long as the jar is charged to the same degree.

Fig. 431.



In the instrument as made, the deflections are shown by a spot of light reflected from a mirror hung above the needle, as in the reflecting galvanometer (145). The Leyden jar is placed in an atmosphere dried by sulphuric acid, and will hold a sensibly constant charge for days at a time. Finally, the metal case screens the needle from all attraction or repulsion by electrified bodies outside, owing to a well-known law. The deflections, being angularly very small, are proportional to the potentials of the bodies to be tested, which are connected with L, while M is kept permanently connected with the earth.

With this instrument, nothing is easier than to compare accurately the times occupied by the charged conductor of a piece of cable covered with water, in falling to half or any other fraction of the charge, and the times thus occupied are relative measures of the insulation resistance of the insulating cover.

In making the test, the cable may be charged by a spark or two from a machine or electrophorus, or it may be charged by simple contact for an instant with a wire joined to one pole of a battery of 50 or 100 elements. The other pole of which is to earth.

The following formula gives the means of calculating in ohms the resistance of the insulator. When the potential P at the beginning and p at the end of a time t measured in seconds are known—

$$R = \frac{t}{S \log._\epsilon \frac{P}{p}}$$

Or,

$$R = \frac{0{\cdot}4343\, t}{S \log. \frac{P}{p}}$$

In the first of these equations the hyperbolic, and in the second the ordinary logarithm of $\frac{P}{p}$ is used, but in both we have a quantity, S, called the capacity of the cable.

(287) **Thomson's Portable Electrometer.**—This instrument is also used for testing the insulating powers of materials, by observing gradual loss of charge from a body insulated by these materials; for testing the electromotive force of batteries and other electromotors, and for various other purposes where great delicacy and accuracy are required.

In a former part of this work (42), mention has been made of this beautiful electrometer. For the following detailed description of it, and the theory of its action, we are indebted to Professor Fleeming Jenkin, F.R.S.:—

It consists essentially of six parts:

1. The Leyden jar, the inner coating of which extends over the lower part of the jar only, and is connected with a brass plate, the upper surface of which is exposed to the air inside the jar, and has no external armature near it.

2. The movable test-plate, parallel with the above, and meant to be connected with the object, the electrical condition of which is to be tested.

3. An index moved by the force exerted between the test-plate and the plate connected with the inner coating of a Leyden jar.

4. An electrode from the test-plate, protected by a cap or covering, which prevents external undried air from entering the Leyden jar.

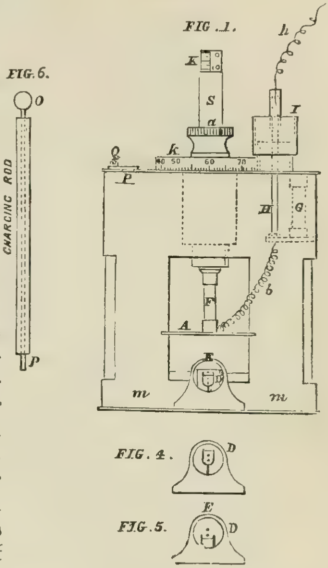
5. A brass covering protecting the contents from external electrical influence.

6. A receptacle for pumice-stone, to be saturated with sulphuric acid for the purpose of maintaining an artificially-dried atmosphere.

The arrangement of these parts will be understood by reference to the two following illustrations (Figs. 432 and 433). The Leyden jar is formed by the glass jar M M (Fig. 433: 2), covered externally by a brass protecting cover with openings, through which the interior can be seen. The external coating of this jar is confined to the lower portion, and is formed by the brass cup $n\,n$ (Fig. 433: 2 and 3), the upper surface of which is coated with a brass plate, N (Fig. 433: 2).

This jar can be charged only by putting a wire, insulated with indiarubber, down through the hole Q (Fig. 432 : 1) in the cover of the instrument. The charge can be given by a succession of sparks from an electrophorus (Fig. 433 : 7 and 8); it may be positive or negative, according to the manner in which the instrument is used. When the charge is given, the wire is withdrawn, and the hole Q closed with a cover. The movable test-plate is marked A A. It is a thin, flat, circular brass plate, carried by a glass insulating column F. This column is carried by a brass cylinder S, which can be raised or lowered by a micrometer screw, worked by turning the nut *a*. The lower flange *k* of this nut is divided into 100 parts. The brass cylinder S projects at its upper end beyond the nut; and on this projection a scale is marked, each division of which corresponds to one turn of the micrometer screw. By this scale, and the divisions on the nut, the distance through which the test-plate is raised or lowered can be read to, say, $\frac{1}{25000}$th part of an inch.

Fig. 432.

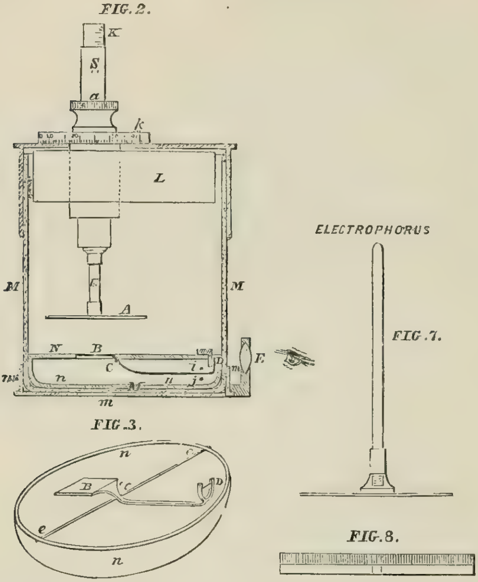


A force of attraction or repulsion will be exerted between the test-plate A and the plate N, according as the two are electrified, similarly or dissimilarly. The force will in any case increase as the test-plate is lowered, and decrease as it is raised. This force is made use of to move the index B C D (Fig. 433).

This index consists: 1st, of a small, square, light aluminium plate B, level with the surface of the plate N: 2ndly, of a bent arm passing under this plate, and carrying a little fork with a cross-hair at D (Figs. 432 : 1, and 433 : 2 and 3). This little fork comes through the cup N *n n*, and can be seen through the glass of the Leyden jar. The index is supported on a fine, light, horizontal wire *e e* (Fig. 433 : 3), on which it oscillates freely within certain limits. The oscillations, indicating the rise or fall of the plate B,

are shown by the fall or rise of the cross-hair D, relatively to two little black spots, marked on white paper immediately behind the cross-hair. When the hair exactly bisects the space between

Fig. 433.



the two spots, as at D (Fig. 432 : 1), it occupies what is called the 'sighted' position, and the plate B is then exactly flush with the surface of N.

To facilitate the observations of the cross-hair, and to avoid parallax, a lens is placed a little distance in front of the spots. When the lens, E, is drawn back from the glass as far as is allowed by the little slide, the hair and spots are seen greatly magnified; and the hair will only appear straight when the eye is in the right position, i.e. exactly opposite the centre of the two spots. The use of this index is to show whether the force exerted between the test-plate and the plate B is such as to bring the plate exactly flush with N. A slight torsion is given to the wire *e e*, in such a direction as, when neither test-plate nor Leyden jar is electrified, will bring the plate B below N, and the cross-hair above the sighted position. The test-plate is electrified by

means of an electrode or terminal H (Fig. 432), which projects through an opening in the brass cover. This electrode is supported by an insulating glass pillar G, and is connected electrically with the test-plate by the wire *b*. A cap or covering, I, slides up and down on the rod H. When pressed down, as it always should be when no test is being made, it excludes the air from the jar at this point, and also connects the test-plate electrically with the outer case of the Leyden jar. When the cap is raised, it forms part of the insulated system of the test-plate, and still serves to prevent any rapid interchange of air between the inside and outside of the jar. The lead case L (Fig. 433) contains pumice-stone moistened with sulphuric acid, for the purpose of keeping up an artificially dried atmosphere within the instrument.

To use the instrument proceed as follows:—Press the cap at I (Fig. 432) down till it touches the cover of the instrument; raise the test-plate by turning the nut *a* till about twenty divisions can be read at the scale at K; uncover the hole in the lid at Q; put the indiarubber-covered wire O P (Fig. 432 : 6) through the hole Q, taking care that the bare copper touches the plate N, and does *not* touch the test-plate A; touch the bare end of the insulated wire projecting from the pole Q with the charged cover of the electrophorus (Fig. 433 : 7); and repeat the operation a considerable number of times, till the cross-hair at *i* drops from above the 'sighted' position to below; then carefully and rapidly withdraw the charging wire, and close the hole Q. The fall of the cross-hair will have been due to the attraction exerted between the plate B, now charged, and the test-plate which is in connection with the earth. The charge on B is sufficient (if the attraction just mentioned is sufficient) to overcome the torsion of the wire, when the test-plate is at such a distance from B as corresponds to twenty divisions on the scale.

Next look through the lens, taking care to keep the instrument to the eye in such a relative position that the hair looks straight and not distorted.

Turn the nut *k* slowly, till the hair comes to exactly the 'sighted' position. When the cross-hair is below the 'sighted' position, the nut must be turned in the direction in which the hands of a watch move; this raises the test-plate, and diminishes the attraction. When the hair is above the sighted position, the nut must be turned the other way. When the cross-hair is exactly in the sighted position, the scale must be read and noted down. Read first the scale at K, and write down the two figures as read, as thousandths and hundredths. Next observe the division on the

nut *k*, opposite the arrow on the lid, and write down the figures as tenths and units. Thus, if 21 divisions are exposed at K, and the division 65 is opposite the arrow on the lid, write down the observation as 21 65; this number is called the *earth-reading*, because the test-plate was in connection with the earth at the time. It serves first to indicate the degree of charge in the Leyden jar; and secondly, as a starting-point from which to measure the difference in the electrical condition of other bodies from that of the earth. Even in the best instrument the earth-reading will not remain sensibly constant when the Leyden jar is first charged; the observer will find that every few minutes he must turn the nut *k* a little round, lowering the test-plate A, increasing the reading. This is due to the gradual partial absorption of the charge into the glass of the Leyden jar. If the jar were suddenly partly discharged, and a new earth-reading taken, this reading would gradually increase, owing to the gradual redelivery of the electricity previously absorbed. For these reasons the jar should be charged for some hours before the instrument is to be used, and the charge should not be disturbed or altered in any way before or during the observations. If the instrument be in good order, the earth-reading will be found sensibly constant about twelve hours after charging, and an observation can then be made.

Raise the little cap I; put the body to be tested in electrical connection with the wire *h*; turn the nut K until the cross-hair is again in the '*sighted*' position. Read the scales as before, and note the result on the last reading. Subtract the earth-reading from the test-reading; the difference measures the *potential* of the body tested. If the difference is *positive*, the electricity of the body tested will be of the same nature as that of the Leyden jar, and *vice versâ*.

Example:—

Let us suppose that the jar was charged by the thin metal disc of the electrophorus, the charge will of course be *positive*. Let the earth-reading be 1,950, and the test-reading 1,210; then the electricity of the body tested is *negative*, and its potential, according to its arbitrary scale differing with each instrument, is 740.

Suppose the test-reading to be 2,320, then the electricity of the body is *positive*, and its potential, according to the same scale, 370.

It is important that the earth-reading should remain constant during each experiment; it should therefore be tested after each experiment, and if it has altered slightly the mean of the initial and final earth-readings should be taken as the true earth-reading.

The body to be tested may be in contact with the electrodes, either momentarily or permanently; if permanently, it is well to use

a fine wire *h* (Fig. 432: 1), slipped into the slit at Q; less risk is then run than with a stronger connection of breaking the electrode or its supports.

To test the electrical qualities of the atmosphere, a slow-burning match may be connected with *h*, or an insulated water-dropper, as described in (43).

Theory of the Instrument.—There are two leading peculiarities in the construction of this electrometer: the *first* depending on an arrangement allowing strict numerical comparisons to be made between any two simple readings taken on the same instrument; the *second* depending on the use of a highly charged and insulated Leyden jar, which greatly augments the delicacy of the indications, and allows the observer to distinguish directly between positive and negative electricity.

The law of attraction between two plane and parallel surfaces, at different electric potentials, forms the basis on which the theoretical proof rests that the readings of the instrument are always comparable.

In a paper by Sir William Thomson (*Proc. Roy. Soc.*, 1860, p. 185), it is shown that the force exerted between two parallel surfaces separated by a distance a, small as compared with their whole area, and maintained at a difference of potential V, will be equal to $\frac{V^2}{8\pi a^2}$ per unit of area. The present instrument contains two plane and parallel discs, sufficiently large, in proportion to the distance separating them, to fulfil the above conditions approximately. This distance can be altered at will. An index is so contrived as to move into a 'sighted' position whenever the force exerted between the two discs is exactly equal to a given amount, constant under constant conditions for each instrument, but varying in different instruments. By a micrometer screw, the difference between any two positions of the parallel planes can be read. One of the planes is maintained at a constant high, but unknown, potential V; the second, which may be called the *test-plate*, is put in connection with the body to be tested. The test is really a comparison of the electric potential of the body to be tested with that of the earth, and is made thus:—The test-plate is first connected with the earth, and moved to such a distance a_1 from the opposite plate, that the index comes to its sighted position. The plate is next put in connection with the body to be tested, and moved to a fresh distance a_2, at which the force between the planes is the same as before, as is shown by the index coming to the same position. Then if x be the potential of the body to be tested, we have—

$$\frac{V^2}{8\pi a_1^2}=\frac{(V+x)^2}{8\pi a_2^2}$$

and therefore—

$$x=\frac{V}{a_1}(a_2-a_1).$$

Now $\frac{V}{a_1}$ is a constant, for as V diminishes or increases, so in an equal ratio will a_1.

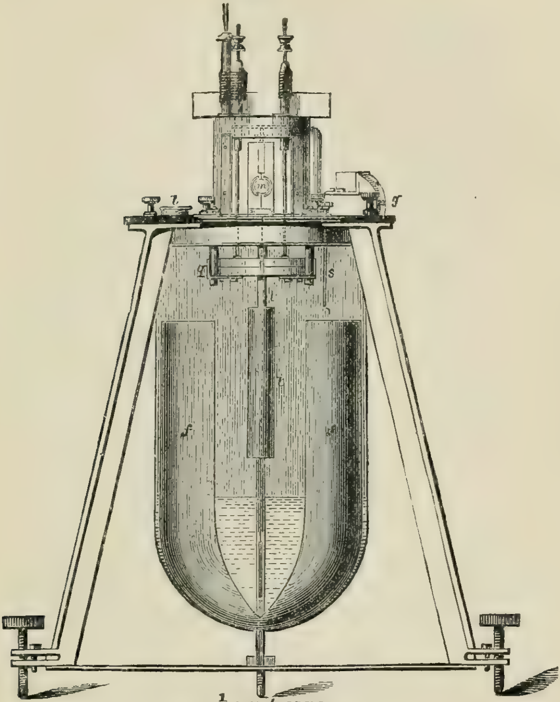
Thus, the above equation shows that in each instrument the potential of the body tested is equal to a constant multiplied into a difference of the distance observed between the two planes as described.

The potential V is that of the Leyden jar already referred to; and the above equations show in what sense the indications are independent of the potential of that charge. They show, however, that the actual force exerted between the planes is increased rapidly as the charge increases; and since this force is employed to move the index, the use of a highly charged plate causes the indications of the instrument to be comparatively very delicate. The use of the jar prevents this charge from varying rapidly, inasmuch as a small leakage affects the potential very little if the whole quantity be large, but would rapidly diminish the potential if the plate of it were not in connection with a store or reserve of electricity. The sign of the difference between a_1 and a_2 gives the sign of the potential of the body tested.

(288) **Thomson's Quadrant Electrometer.**—This is a further and great improvement on the previous electrometers. Its value is increased for observing purposes by the addition of a small mirror *m*, which converts it into a 'reflecting' electrometer, allowing it to be used in a similar manner to the reflecting galvanometer. This instrument has proved of the greatest value in submarine cable testing, and its use has become greatly extended. Fig. 434 explains the general appearance of the instrument. By far the greater bulk of the instrument is the jar of white flint-glass. This is supported on three legs by a brass mounting, cemented round the outside of its mouth. The latter is closed by a plate of stout sheet-glass, with a lantern-shaped cover standing over a wide aperture in its centre. Beneath the cover, and within a circular metallic box, cut twice at right angles, so that the separate parts form quadrants, is placed a thin aluminium needle, whose shape somewhat resembles that of a double canoe-paddle. The needle at its centre is rigidly fixed to an axis of stiff platinum wire in a plane perpendicular to itself. At the top end of the wire a small cross-piece is fixed, to the extremities of which are

attached the lower ends of two suspending silk fibres, the other ends being wound upon two pins, which may be turned in their sockets by a square-pointed key. By this means the tension of

Fig. 434.



$\frac{1}{4}$ real size

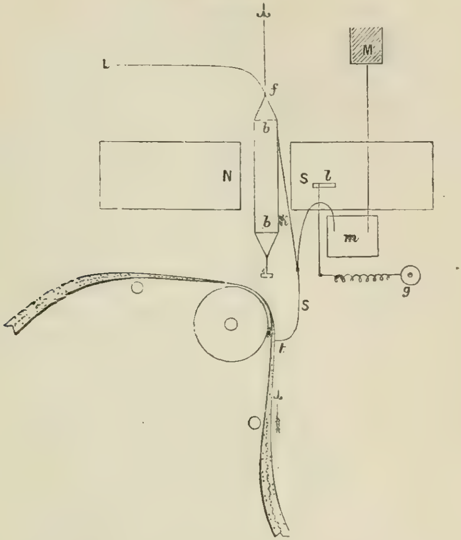
the fibres can be equalised and the needle caused to stand midway between the upper and under surfaces of the quadrants. The two silk fibres form what is termed the bifilar suspension, which has now superseded the single fibre and magnets of the original instruments. In the earlier forms a magnetic adjustment similar to that in the mirror galvanometer was employed to bring the needle to zero, but the bifilar suspension has been found to secure this result in a much more advantageous way. The pins are pivoted in blocks carried by springs, to allow them to be shifted

horizontally when adjusting the position of the points of suspension. The ends of the screws which traverse these blocks rest against the fixed plate behind, so that, when either is turned in the direction of the hands of a watch, the neighbouring point of suspension is brought forward, and conversely. The needle may thus be brought to lie in such a position that the quadrants are symmetrically placed about it. Finally, by turning the conical pin (which passes between the two springs and screws into the plate behind) to the right or left, the points of suspension are made to recede from or approach each other, and thus the sensitiveness of the needle is decreased or increased, within certain limits, at pleasure. Just below the cross-piece is fixed the mirror, which, like the galvanometer, reflects the movements of the needle upon a scale placed at a certain distance in front of it. The needle itself is electrically connected with sulphuric acid in the bottom of the jar by means of a fine platinum wire hanging from its lower side, and kept stretched by a platinum or leaden weight below the surface of the liquid. It will thus be seen that the charge of the jar is communicated to the needle, and the higher the charge the more sensitive the needle becomes. The acid serves a double purpose; it keeps the air dry within the jar, and forms also the interior coating of the same. As the wire which dips into the acid passes through a guard tube, any lateral deviation of the needle and its appendages is prevented, and liability to accident thereby much reduced, while at the same time the whole reflecting system has perfect freedom of motion round a vertical axis. Lateral and micrometric movements of the quadrants are both used for varying the adjustment of the instrument, and in some of the latest forms an induction plate has been added, which permits the instrument to be used for a greater range of measurement.

(289) **Thomson's Syphon Recorder.**—This instrument was invented by Sir William Thomson for working long submarine cables, and it is now used upon nearly every ocean cable. It possesses great delicacy, and has met with deserved success. The syphon recorder is so arranged as to actually depict on paper the apparently irregular movements of the galvanometer needle. A fine glass syphon tube, *s*, conducts the ink from a reservoir, *m*, to a strip of paper, which is drawn past the point of the tube *t* with a uniform motion. The point moves to the right or left of the zero line through distances proportional at each instant to the strength of the current, and thus the signals are drawn on the paper in the form of curves, representing the strength of the current at each instant of time. The apparatus consists of a very

light rectangular coil, *b b*, of exceedingly fine insulated wire, suspended between the poles of a large and powerful electro-magnet,

Fig. 435.



N S, charged by a local battery of large size. Within the core is a stationary soft-iron core, which is powerfully magnetised by induction from the large electro-magnet. The coil swings upon a vertical axis, consisting of a fine wire whose tension is adjustable. The received current passes from the line L through the suspended coil, *b b*, the suspension wire, *f*, acting as the conductor; the coil is impelled across the magnetic field in one direction or the other, according to the polarity and strength of the current passing through it. The magnetic field in this arrangement is very intense and very uniform, which makes the apparatus sensitive to the weakest currents. The syphon consists of a fine glass tube turning upon a vertical axis; the shorter end is immersed in a reservoir of ink, *m*, and the longer end rests upon the recording paper. The syphon is pressed backward and forward in one direction by a thread, *k*, attached to the swinging coil, and in the other by means of a retracting spring, *g*. The paper is caused to move at a uniform rate by means of gearing driven by a small electromotor.

The adjoining figure (436) is an exact copy of the writing of the syphon recorder.

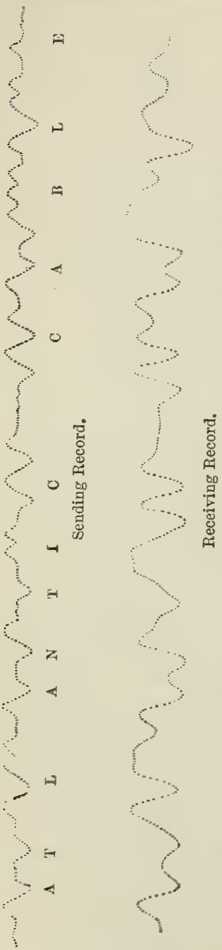


Fig. 436.

In working very long cables the action of the current upon the swinging coil is very feeble, and the friction of the syphon against the paper strip, if allowed to come in actual contact with it, would interfere with the freedom of its movements. In such cases the point of the syphon does not actually touch the paper; friction is avoided. The ink and the paper are oppositely electrified by means of an electrifying machine, driven by the same electromotor which moves the paper. The electrical repulsion causes the ink to be ejected from the syphon upon the paper in a succession of fine dots. M is the electrifying machine, which keeps the ink constantly charged with electricity, and, being thereby repellent of its own particles, causes a constant stream of ink to be spurted out upon the paper as it passes in front of the open end, *t*.

Fig. 437 shows how two such recorders are joined up for working the one at the sending station—say, Valentia—and the other at the recording station—say, Newfoundland. The key is worked like that of a single-needle instrument (231). When the right key is depressed it charges the home side of the condenser with positive electricity, which sends a positive current to the receiving station. When the left key is depressed the reverse takes place. A small portion of the current in each case passes through the home apparatus, so as to record what is sent. Condensers are used at each end to prevent any disturbance from earth currents—a plan that was invented by Mr. Cromwell Varley.

(290) **Detection of Faults in a Submarine Cable.—**

(*Fleeming Jenkin, Cantor Lectures.*)—Faults in cables may arise: 1. From a fracture or interruption in the copper conductor, which

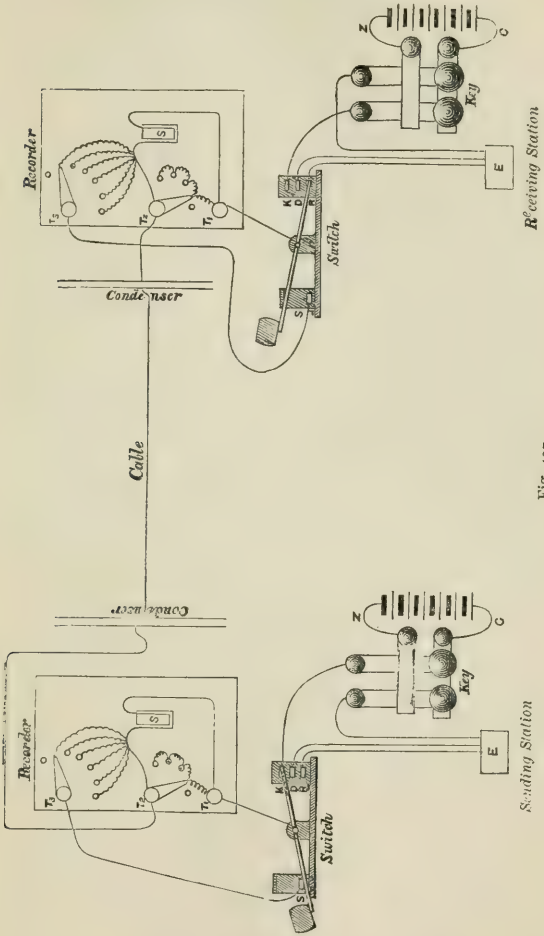


Fig. 437.

nevertheless remains insulated inside the gutta-percha covering. 2. From a fracture of the copper conductor and gutta-percha, in

which a considerable length of copper wire remains exposed to the water. 3. From the copper wire and gutta-percha being both broken, but little copper exposed. 4. From the establishment of a connection between the iron covering and the copper core by a nail or wire driven in. 5. From a hole in the gutta-percha sheath establishing a connection between the conductor and the sea.

The position of the *first* of these faults, which is of course followed by a total cessation of all communication between the two ends of the cable, may be detected in two ways. The charge which the cable will contain is first measured (282), and if the charge per knot is known, the amount actually observed will directly give the distance of the break; and the accuracy with which the position of the fault can be determined is limited only by the accuracy with which the relative charges can be compared. Suppose, for example, the discharge from a knot of the cable, with a given battery and reflecting galvanometer, is represented by a deflection of 10 divisions, and a discharge from a cable containing a broken copper conductor is 100 divisions, we may feel certain that the fault is about 10 miles from the shore. Or, secondly, the resistance of the insulating sheath may be measured. Thus, if we know by the discharge test that the cable is insulated where broken, and find the insulation resistance to be 1,000 units, whereas the insulation resistance of one knot is 1,000,000 units, we may conclude that the fault is 1,000 miles off, as it will require 1,000 miles of sound core to give so small a resistance as 1,000 units.

A fault of the *second* kind likewise wholly stops communication between the two ends of the cable. In this case the resistance of the copper conductor measured from the shore measures the distance of the fault. We know the resistance per knot, and if we observe 500 times the resistance, the fault is 500 miles off, the resistance of the earth itself being *nil.*

The *third* class of fault is where the connection between the sea and the copper exists, but is imperfect, or due to only a small area of exposed copper. It possesses considerable resistance, sometimes more than that of all the copper conductor of the cable; and what is worse, this resistance is inconstant, varying rapidly and capriciously between extremely wide limits. The test for resistance in that case simply tells us that the fault cannot be beyond the distance corresponding to the smallest resistance observed.

The *fourth* kind of fault corresponds almost exactly in behaviour to the second, but the connection with the sea is still more perfect. The resistance will vary still less; and there will be a total absence

of the feeble currents which result from the copper and iron of a cable when broken and separated by salt water.

The *fifth* kind of fault is easily detected. There is a considerable fall in the insulation resistance, and a slight or moderate fall in the apparent resistance of the copper conductor between the two stations; but messages can still be transmitted, as a portion only of the whole current inversely proportional to the resistance of the fault escapes into the sea. If one station insulates the cable, and the other measures the resistance, the fault behaves like a fault of the third class, and this test will not detect its position. If, however, one resistance of the fault remain constant, and two measurements of resistance, R and r, be made from station A, when station B respectively insulates the end of the cable and connects it with the earth, we obtain two equations, concerning the resistances in which there is only one unknown quantity—viz. the resistance of the fault. When this is eliminated, the following equation is obtained:—

$$D = r - \sqrt{(R-r)(L-r)}$$

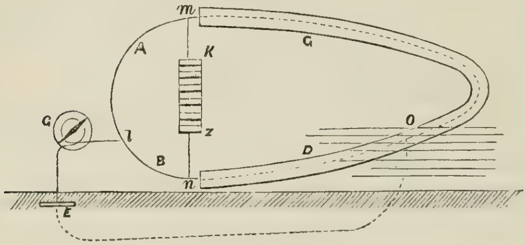
where D = the resistance of the conductor between the fault and the observer, and L = the resistance of the whole conductor between the stations. Successive tests from the two stations, the distant end being insulated in each case, will also give two equations, by which, on the same supposition that the resistance of the fault remains constant, its position can be determined. Then calling R and R_1 the resistance in the two cases, we have—

$$D = \frac{L + (R - R_1)}{2}.$$

When D is the resistance of the conductor between the station which observed the resistance R and the fault, and when a return insulated wire can be substituted for the earth, so that the observer has both ends of a complete metallic circuit before him, the position of a fault such as is described, even of a varying resistance, can be accurately determined. Varley uses a differential galvanometer to ascertain when an equal current runs into both ends of the metallic circuit and out at the fault. This will only be the case when the resistance between the galvanometer and the fault is the same by both roads. This condition is easily fulfilled by adding resistance coils between one coil of the galvanometer and the defective wire. The resistance which must thus be added, to bring the galvanometer to zero, is obviously equal to twice the resistance of the metallic conductor between the fault and the distant station. Wheatstone's balance (110) may be so arranged as to give another

method, by making the connections as in Fig. 438, where the fault, supposed to be at *o*, forms, as it were, part of the galvanometer wire. In this case, as in the preceding, a variation in the resistance of the fault does not affect the result; it will cause a greater or less deflection of the galvanometer until the desired

Fig. 438.



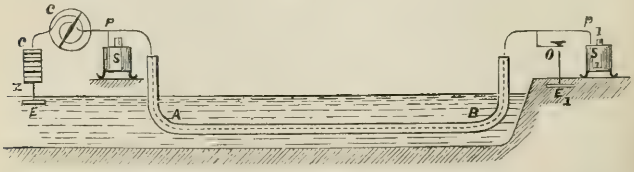
balance is effected; but it will not alter the relative resistance of the several parts of the main circuit required to reduce the deflections to zero.

The test is made by adjusting the relative resistances of A and B until no deflection is obtained; then the fault will be at a point such that $\frac{A}{B}=\frac{C}{D}$, where C and D represent the resistance of the conductor separating *m* from the fault and *n* from the fault. When the total resistance of the conductor is known, this will give the positions of the fault very accurately.

Mr. John Murray, of Glasgow, is said (*F. Jenkin*) to have first applied this test on board the Niagara, during the first Atlantic expedition. It was re-invented by F. Jenkin, and may be used to detect very small faults, even on short lengths.

Another plan of determining the position of a fault of this nature, is the joint invention of Sir William Thomson and Mr.

Fig. 439.



Fleeming Jenkin (*Cantor Lectures*). The connections required are shown in Fig. 439, where G is a galvanometer; S an electro-

meter at the same station; S_1 an electrometer at a distant station, where the end of the submerged cable, A B, is insulated. The battery $c\,z$ is connected with the other end of the cable. Then let c = the current observed at the galvanometer; V = the potential at the distant station; b = the length of the cable; K = the resistance of the unit lengths of the conductor; n = the resistance of the unit length of insulator to conduction across the sheath; and let

$$\sqrt{\frac{K}{n}} = a.$$

All these quantities may be known, and should be measured in the so-called absolute units, or other equally coherent system. Let λ be the distance of the fault from the ship or galvanometer station: then—

$$\lambda = \frac{1}{2a} \log._\epsilon \frac{F}{D},$$

when

$$F = V + \frac{K}{a}c - U\epsilon^{al},$$

and

$$D = U\epsilon^{-al} + \frac{K}{a}c - V.$$

Undoubtedly this test is not of so simple a nature that it could be executed by a clerk, but it is interesting to know that a test does exist by which even a fault of this description, which has hitherto baffled electricians, can have its positions fixed with mathematical certainty. This is the more important, as the connections shown in the figure are precisely those which are the best adapted for test during the submersion of a cable. The marine galvanometer G would give one test of insulation, the electrometer S a second one, the electrometer S_1 a third test on shore. The shore would speak to the ship without causing a suspension of the insulation test, either on S or G; and even when the ship speaks to the shore, the electrometer S will maintain the insulation test, as it is not affected, like the galvanometer, by the rush of the current in and out of the cable, as it is partly discharged or additionally charged by the withdrawal or addition of part of the battery power. The electrometers have, on the same grounds, a superiority over the galvanometers in their behaviour under the influence of earth-currents or the rolling of the ship.

(291) **Another Method of Testing Faults.**—This is a method adopted in 1867 by Mr. Lumsden, and used with much success; it was, however, first tried at Aden in 1862 by Mr. J. C. Laws, but the results obtained by Mr. Lumsden were arrived at quite independ-

ently. This method of testing for the distance of a break in a submarine cable is based on the following facts :—

When a submarine cable is broken, the end of the copper conductor is generally exposed in the sea water. Under these circumstances, if a positive current is sent into the wire, the exposed end becomes gradually coated with salts of copper, from the reduction of the metal, and a polarisation current is set up in the reverse direction, opposing the testing current. If a negative current is now sent into the wire, it will gradually reduce the copper salts, and the end will become coated with soda, while hydrogen is evolved—the polarisation current being reverse. But no hydrogen will be evolved, and therefore no negative polar current will be set up, until the instant when the whole of the copper salt has been reduced. At this instant the polarisation currents must be neutral, and if a test could be taken quickly enough, it would give the true resistance of the wire to the fault; but the change is so sudden, and the increase in resistance due to the opposing polarisation current from the hydrogen becomes at once so great, that this in the ordinary way is impossible. Mr. Lumsden, therefore, conceived the idea of making the appearance of the negative polarisation current itself give the indication by which the true resistance could be obtained with a differential galvanometer, as follows :—

After cleaning the end, so as to obtain as large a surface as possible exposed to the sea water—by keeping a strong negative current on the wire for some hours, with occasional copper reversals—

1. Coat the exposed end with copper salts, by keeping a positive current on the wire from one to two minutes.

2. Reverse the batteries, so as to test with a negative current, and alter the resistance of the coils, so as to bring the needle to zero. As the (+) polarisation current from the copper salt will be in the same direction as the (–) testing current in that half of the galvanometer connected to the cable, the effect will be to make the resistance of the cable appear less than it should be; but as the copper salt becomes gradually reduced by the (–) testing current, the (+) polarisation current will also gradually decrease, and the apparent resistance will increase. The resistance in the coils must therefore be gradually increased unit by unit, *so as to keep the needle at zero* until that point is reached when the whole of the copper salts have been reduced and hydrogen is evolved, the (–) polarisation current from which, opposing the (–) testing current, causes a *sudden* and enormous increase in the resistance, which is shown instantaneously by the *sudden* deflection of the needle. The resistance in the coils at this moment will be the true resistance of the

wire to the fault, the resistance of the end being altogether eliminated.

The battery-contact key should be depressed during the entire test, which should be taken with, say, 60 cells, for if a very small power be used the sudden deflection of the needle is not so marked; but if the exposed end is very short 60 cells (–) may reduce the copper too rapidly, so that there is no time to adjust the resistance coils. The proper amount of battery power may be easily ascertained from one or two trials. As a guide to give an idea of what the true resistance is:—after coating the end with copper salts from a (+) current, reverse the batteries and take an immediate reading with the (–) current. This will be less than the true resistance. Then, keeping the battery contact made, take a reading after the copper has been reduced (or take the maximum resistance with a (–) current). This will be higher than the true resistance. The real resistance lies somewhere between these two.

CHAPTER XIX.

ELECTRIC TELEGRAPHY (*continued*).

DUPLEX AND QUADRUPLEX TELEGRAPHY.

Duplex: Historical—Duplex Principle—Differential Method—Bridge Method—Key Arrangement—Use of Condenser. Quadruplex: Historical—Edison's System—Gerritt Smith's Relay—Pole Reverser.

(292) **The Duplex System.**—The possibility of transmitting two messages in opposite directions at the same time on the same wire was proved as early as 1853 by Dr. Gintl, director of the Austrian States Telegraphs, and subsequently by Frischen, Siemens and Halske, Preece, and others. At that early date telegraphy had not become developed to such an extent but that the ordinary methods of single transmission were found to be amply sufficient to carry on all the work that had to pass over the lines then erected; the invention of 'duplex' telegraphy, as the method is now termed, was therefore looked upon as a mere scientific curiosity.

Between the years 1868 and 1872 Mr. J. B. Stearns, of Boston, America, turned his attention to the subject, in consequence of the increase in the work which passed over the lines of the American telegraph companies, necessitating increased means of communication. The result was that duplex telegraphy was roused from the oblivion into which it had fallen and was introduced with great success.

The English and other European telegraphic administrations were not slow to follow the example set, and at present the value of the invention is abundantly recognised; indeed, the ever-increasing work of telegraphic business is enabled to be efficiently carried on by its means with a far smaller number of wires than would be the case if the ordinary method of single transmission only were available.

In order to understand the principle of the duplex system, the popular notion that the signals transmitted at each end of the wire actually cross one another, and are received at the further ends without producing interference, must be cast aside; no such supposition is necessary to explain, or does explain, the principle of duplex tele-

graphy. It is no more possible to transmit two distinct currents of electricity in opposite or the same directions through a wire, than it is possible to send two distinct streams of water through a pipe in opposite or the same directions. Indeed, as will be seen, the principle of the duplex system depends upon the fact that when two currents of opposite signs are opposed to one another, they produce a neutral effect.

Like all other systems, the duplex method of transmission has been effected in various ways, and has been applied to various kinds of apparatus. As most of these are in but very limited use, two only, which are now very generally employed by all telegraph administrations throughout the world, will be described—viz. the 'differential' and the 'bridge' duplex systems, applied to the Morse instrument.

Fig. 440.

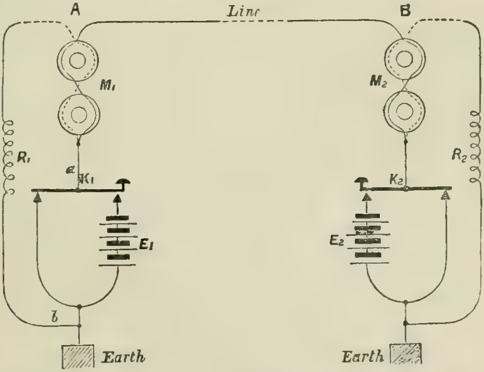


Fig. 440 shows the former of these methods—viz. the 'differential' method—which is, in fact, the one originally invented by Frischen.

M_1 and M_2 are the electro-magnets of the receiving instruments at the stations A and B. These electro-magnets are each wound with two wires of equal length and diameter, and consequently of equal resistance.

An electro-magnet so wound can be excited and caused to work the instrument of which it forms a part if—

1. Currents pass through either of the coils in either direction.

2. Currents pass through each coil in the same direction, the strength of the current in one coil being either equal or unequal to that in the other.

3. Currents pass through each coil in opposite directions, the current in one coil being greater than that in the other.

If, however, currents pass through each coil in opposite directions, the current in one coil being equal to that in the other, then no effect will be produced.

In what way can these conditions be applied so as to effect duplex transmission?

Suppose the key K_1 at station A to be depressed, then a current will flow from the battery E_1, a portion going though one coil of M_1, and through a resistance R_1, to earth; the other portion of the current will go through the other coil of M_1 and out to line. As the connections are so made on to M_1 that the currents through the coils flow in opposite directions, and as R_1 is adjusted so that these currents are equal, the electro-magnet M_1 is unaffected.

The portion of current flowing out to line passes through that coil of M_2 to which the line is connected, and thence goes to earth through the back stop of the key K_2; M_2 being then under the condition specified in 1, consequently responds.

If B were the transmitting station, then it is evident that M_1 would respond, but not M_2.

Now suppose that both keys are depressed; in this case, as the two similar poles of the batteries are connected to one another, no currents can pass through either of those coils of the electro-magnets which are connected to the line; currents, however, flow through each of the other coils, and both instruments consequently respond.

There is still another condition of the keys to consider, and that is, when one key being down the second commences to be depressed and leaves its back stop without touching the front stop. In this case, at the station where the second key is placed, the current, instead of passing to earth through one coil of the instrument, passes through both coils and gets to earth through the balancing resistance; but, as it passes through the coils in the *same* direction, the condition of affairs is that stated in 2. The instrument, therefore, still remains affected.

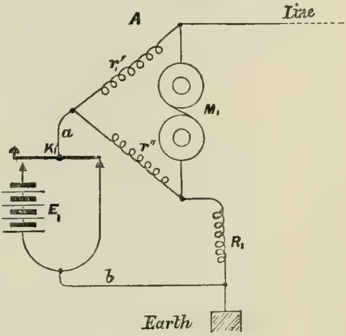
At the other station the current flowing through the coil of the electro-magnet connected to the line becomes reduced in strength, in consequence of its having to pass through a greater resistance than was the case at first. The condition of affairs in this case is that stated in 3; consequently the instrument at this station commences to respond; when the key has become quite depressed, we get the condition that has been before discussed.

It will easily be understood that an essential element of success in the system lies in the adjustment of the resistances R_1 and R_2; it is necessary that this adjustment should be such that

the currents passing through the two coils of the electro-magnet at one station, when that station alone is transmitting, are equal. As the resistance of the line is subject to continual alteration from climatic influences, the resistances R_1 and R_2 are made adjustable, so that balance can always be preserved.

In the figure and description it has been assumed that the batteries E_1 and E_2 are so arranged that when the two keys are depressed similar poles are connected together, and no current passes out to line. This arrangement of the batteries is not, however, essential to the working of the system, as it will work equally well with one of the batteries reversed, so that when the two keys are depressed the opposite poles of the batteries become connected. In this case, instead of there being at each station a current passing through one coil of the magnet only, there will be an equivalent effect produced, by twice as much current passing through one coil as through the other; the working of the apparatus will therefore be exactly the same in the two cases.

Fig. 441.



The 'bridge' duplex system is shown by Fig. 441, one station, A, only being represented.

In this arrangement the instruments do not require to be double-wound, a balance being obtained by the adjustment of three resistances, r_1', r'', and R_1. To obtain this balance the relative values of these resistances must be such that

$$r_1' : r'' :: L : R_1,$$

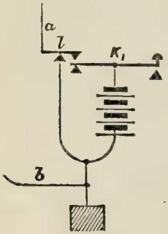
L being the resistance of the line plus the resistances at the further station, B. A like proportion is also given to the resistances at B.

Practically, in order to allow for variations in the resistance of the line from climatic changes, it is sufficient to adjust the resistance R_1 and the corresponding resistance at station B, the other branch resistances remaining unaltered.

It is unnecessary to consider the way in which the movements of the keys control the currents in the foregoing arrangement, as it is substantially the same as in the differential method.

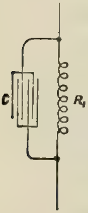
In describing the differential duplex it was pointed out that if key K_2 was down, K_1 being up, then the course of the current was such as to work M_1, and that if K_1 was then depressed, sufficiently only to disconnect it from its back stop without making contact with its front stop, the course of the currents would still be such as to keep M_1 affected. The effect on the magnet in the two cases is, however, unequal, and this tends to make the signals received on the instruments somewhat irregular, though, as a rule, not sufficiently so as to interfere with the working. In order to remedy this defect the transmitting keys are sometimes so arranged that contact is not broken from one stop until contact is made with the other stop. Such a device is shown by Fig. 442. In this arrangement l is a short lever, which normally rests on a contact connected to earth and one pole of the battery. The lever of the key itself is connected to the second pole of the battery. On depressing K_1 it first makes contact against the lever l, and then disconnects the latter from the stop against which it normally rests.

Fig. 442.



A defect in the duplex systems described, of a much more serious nature than that due to the key, was found to exist when they came to be tried on long lines. This was due to the fact that when the key at either station was depressed, the current flowing through the line induced a static charge in the latter; and this charge, when the key was allowed to fall back, discharged itself through the instrument and produced a false signal. On short lines this discharge was not sufficiently great to interfere with the working of the apparatus, but when the lengths of the circuits were as great as three or four hundred miles it was found impossible to ignore the existence of the discharge. This serious practical difficulty was not overcome till the year 1872, when Mr. Stearns added a *condenser* to the balancing resistance and effectually solved the problem. The principle upon which the condenser acts is simply that of assimilating the balancing resistance, or 'artificial line,' as it is usually termed, to the line, by making it possess both the elements of resistance and capacity for holding a charge. The way in which the condenser C is connected with the artificial line R_1 is shown by Fig. 443.

Fig. 443.



(293) **The Quadruplex System.**—'Quadruplex' is the term applied to the system of telegraphy which enables four distinct

messages, two in one direction and two in the other, to be transmitted at the same time through one wire.

The problem to be solved, in order to enable this result to be effected, is the transmission of two messages in the *same* direction at the same time through one wire; this being accomplished, it can be proved that the application of the duplex principle to such an arrangement presents no difficulty whatever.

The first attempt to solve the problem was made by Stark, of Vienna, in 1855. The principle of his system was that of causing one transmitting key to send a current of a certain strength, which worked one relay; the second key transmitted a current of a greater strength, which worked a second relay, but which did not affect the first, whilst when both keys were depressed a current equal in strength to the sum of the two currents sent by each key caused both relays to respond.

Now it is evidently an easy matter to adjust a relay so that it shall be worked by a strong current and not by a weak one; it is not, however, so easy to cause a relay to be affected by a weak current and not by a strong one. Yet this is what had to be effected in order to solve the problem by Stark's theory.

Stark attempted to do this by causing the relay which was worked by the strong current to transmit a counterbalancing current from a local battery through the relay which was worked by the weak current, and so counteract the effect of the strong current. This device, however, was defective, inasmuch as the counterbalancing current did not commence to circulate through the coils of the relay in question until the tongue of the relay worked by the strong current had passed from the stop against which it usually rested to the other stop, and during this time the tongue of the other relay would have made a similar excursion, and have produced a signal before the counteracting current came into play.

Subsequently to 1853 other attempts to effect the object in view were made by Siemens, Kramer, Bosscha, and others, with, however, but very little success, and it was not till 1874 that any really practical results were obtained. During that year a system devised by Mr. Edison was successfully operated upon the lines of the Western Union Telegraph Company in America, and from that date 'quadruplex' telegraphy became an accomplished fact.

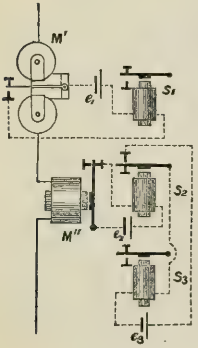
The principle of Mr. Edison's method is as follows:—

One of the keys at the transmitting station is so arranged and connected to a battery, that it transmits alternate negative and positive currents on being alternately depressed and raised. The second key, on being depressed, increases the power of the battery

connected to the first key, so that both the positive and negative currents transmitted by the latter are increased in strength.

At the receiving station two relays are placed—one of the Siemens polarised form, whose tongue moves to and fro and works the instrument connected to it, when its coils are traversed by either weak or strong alternate negative and positive currents. The second relay is an ordinary soft-iron one, unpolarised, and whose armature is attracted and works the instrument connected to it, if its coils are traversed by either positive or negative currents, but which is so adjusted as to be only affected by strong currents. By this arrangement the movements of the first key work the polarised relay whether the second key is depressed or not, whereas the unpolarised relay only responds when the positive and negative currents transmitted through its coils by the first key are strengthened by the depression of the second key. Fig. 444 shows the arrangement of the relays and the connections of the local batteries with the instruments.

Fig. 444.



M′ is the polarised Siemens relay, and S_1 the instrument (a sounder) worked by means of the local battery e_1.

M″ is the unpolarised relay which works the instrument S_3 by means of the local battery e_3. It will be observed that S_3 is not worked direct from M″, but that an intermediate instrument S_2, itself worked by a local battery e_2, is introduced. The working of the arrangement, in fact, is as follows:—

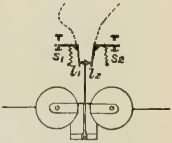
When the armature of M″ is attracted, it breaks the circuit of the local battery e_2 and the instrument S_2, consequently the armature of the latter, which is normally held down, rises and completes the circuit of e_2 and S_2. The latter instrument, therefore, responds.

The object of this arrangement is to avoid a difficulty which would otherwise cause certain of the received signals to 'split.' When the current which is traversing M″, and holding its armature down, is suddenly reversed by the depression or raising of the key which sends reversed currents, this armature will cease to be attracted at the instant that the reversal occurs, and therefore will fall back for a moment against the stop on which it normally rests. If, then, the instrument S_3 were worked direct from the contact stop against which the armature is attracted, it is evident that it would respond to this movement of the armature when it is not required to do so, and would cause false signals to be given. By adopting

the device described, however, although the armature of M″ moves back against its back stop for a moment, it must reach the latter, and remain there sufficiently long to allow the circuit of S_2 to be completed, before S_3 can be caused to work. This back movement is, however, too rapid to allow the completion of the circuit to take place, and therefore S_3 is not affected.

Although the unpolarised relay M″ is found to work fairly well on short lines, its action becomes uncertain and sluggish on lines of a greater length. Mr. Gerritt Smith, assistant electrician of the Western Union Telegraph Company at New York, has effectually overcome these defects by the invention of the ingenious form of relay shown by Fig. 445.

Fig. 445.



This relay is essentially of the same form as M′ (Fig. 444), but instead of the tongue playing between two fixed stops it normally touches two small levers, l_1, l_2, which are in the circuit of the instrument S_2 (Fig. 444). These two levers are held against stops, in the position shown, by springs, s_1, s_2, so that normally, as with the unpolarised form of relay, the circuit of S_2 is kept closed. When, however, a strong current of, say, positive polarity traverses the coils of the relay, then the tongue moves to one side and overcomes the antagonistic force of the spring attached to the lever on that side, and by moving the latter breaks the circuit of S_2. If now the current is reversed the tongue of the relay moves over to the other side and actuates the second lever; the circuit of S_2 therefore continues broken. It is true that in moving from one side to the other the tongue passes the point at which it touches both levers, but the interval during which it does so is so extremely brief that no appreciable effect is produced on the instrument S_2.

The springs s_1 and s_2 are of course tightened up to such an extent as to prevent the tongue of the relay moving with weak currents.

In actual practice the transmitting keys do not directly regulate the transmitted currents, as it is found that if they are caused to do so irregular contacts are made, unless the 'keying' is very firmly done. The current-reversing arrangement, or 'pole changer,' as it is called, and the current increaser, are therefore worked by the armatures of electro-magnets, which are themselves worked by the transmitting keys with local batteries.

The current transmitters and the relays at each station are arranged with resistance coils and condensers in a similar manner to the relay and key in the bridge duplex, shown by Fig. 441. The whole apparatus so arranged forms the Quadruplex.

Several modifications of the apparatus have been devised from time to time, but they are all based upon the principles involved in the system which has been described. Systems have also been invented for transmitting a greater number of messages than four at the same time on the same wire, but as yet the success obtained has not been such as to justify the invention being considered of practical value.

CHAPTER XX.

ELECTRIC TELEGRAPHY (*continued*).

THE TELEPHONE AND MICROPHONE.

Transmission of Musical Sounds—Reiss's Apparatus—Wright's Receiver—Varley's Receiver—Gray's Telephone—Bell's Speaking Telephone—Edison's Carbon Telephone—Hughes's Microphone.

(294) **The Telephone.**—The transmission of musical sounds through a telegraph wire by electrical means appears to have been first effected by Reiss, of Friedrichsdorf, in Germany, in 1861. His apparatus comprised a transmitter and a receiver. The transmitter was a square wooden box with two round holes in it, one on the top and the other in front. The hole at the top was closed by a thin and tightly stretched membrane. In the hole in the front of the box was fixed a large speaking-tube mouthpiece. Any sounds produced or uttered at the latter would set the air in the box in vibration, and these vibrations would be communicated to the membrane, which would also vibrate. A small piece of platinum, cemented to the centre of the membrane, was connected to a terminal fixed on the box. Resting, by its own weight, on the piece of platinum was a platinum point connected with a second terminal fixed on the box. With this arrangement, every time the membrane vibrated the platinum point was jerked off the platinum piece on which it rested, and thereby broke contact between the two. As the number of vibrations made by the membrane in a second varied with the *pitch* of the note sounded near the mouthpiece, so did the number of cessations of contact between the platinums vary. The receiver for this apparatus was formed of an iron rod, whose ends were fixed on wooden supports attached to a sounding board ; a coil of wire surrounded this rod without touching it. When a current was sent through the coil, the rod, being thereby magnetised, became slightly lengthened, and on the

cessation of the current this elongation ceased. This vibratory movement of the rod caused a 'tick,' called the 'magnetic tick;' and if by making and breaking contact with great rapidity these vibrations were caused to succeed one another at very short intervals of time, then a musical note, or continuous sound, was produced, the pitch of the note varying with the rate of the vibration. By joining up this sounding arrangement in circuit with a battery and the transmitter first explained, the pitch of any note sounded at the mouthpiece was produced in the receiver.

A more effective form of receiver than that described has been employed by Dr. Wright. This consists of a *condenser*, formed of two sheets of paper, silvered on one side only, and laid together so that the unsilvered sides are together. Each sheet is connected to one end of the secondary wire of an induction coil, the primary wire of which is in circuit with a battery and the Reiss transmitter. Every make and break in the primary circuit caused by the vibration of the membrane produces a charge and discharge in the condenser, each being accompanied by a sharp snap of considerable loudness. Mr. C. F. Varley has employed a similar receiver, viz. a condenser formed of sheets of tin-foil, separated by insulating sheets of paper and laid loosely together.

Sounds vary in *pitch*, *intensity*, and *quality*. The pitch depends upon the number of vibrations that occur in a given time; the intensity depends upon the amplitude or length of those vibrations, and the quality is determined by the form of the vibrations.

In Reiss's telephone the pitch of a sound only can be reproduced; intensity and quality, unless indeed they do not vary, must be absent.

In 1874 Mr. Elisha Gray, of Chicago, America, succeeded in effecting the transmission, through a wire, by means of electricity, of the variable intensity, as well as the pitch, of a sound. Subsequently he invented a form of telephone by which all the three characteristics of sound could be transmitted. As a result, the electrical transmission of articulate speech became an accomplished fact. It remained, however, for Professor Graham Bell, of the Boston University, to accomplish this latter feat in the most effective manner.

In order to understand the principle of Professor Bell's invention, let us suppose a flexible iron plate to be fixed at one end, and let there be placed near the other end, and close to the surface of the plate, the poles of an electro-magnet; by causing then intermittent currents to succeed one another at a regular rate through the coils of the electro-magnet, the plate will be caused to vibrate in unison with these currents, in consequence of the alternate attractions and cessations of attraction of the plate by the pole of

the electro-magnet, and a sound will be produced. If the pulses of current be caused to follow one another at different rates, but at the same time be preserved of equal strength, then, although the *pitch* of the note will be varied, its intensity and quality will remain unaltered. If, however, the strength of the current be varied, then the amplitude of the vibrations will be varied, and with it the intensity of the sound given out by the plate. Lastly, if during the time any particular vibration is being made by the plate the intensity of the current be varied, but varied in such a manner that the time occupied by the vibration remains unaltered, then the form of the vibration will depend upon the way in which this variation takes place, and upon the form which the vibration takes will depend the quality of the sound given out by the plate.

By varying, then, the currents so as to cause the plate to be vibrated in any particular manner, the three characteristics of sound can be reproduced. Inasmuch, however, as the movements of an iron, or indeed of any plate, cannot be perfectly controlled by the currents, the relative, and not the exact, form of the pulses of current will be imparted to the plate; in other words, the material and form of the plate will, to a certain extent, determine the quality of the sound given out, but will not extinguish the quality due to the form of the pulses of current.

Now, the movement of an armature in front of the poles of an electro-magnet, through whose coils a constant current from a battery flows, induces magneto currents in the coils. If the armature be moved rapidly backwards and forwards from and to the poles, then a proportionately rapid succession of currents will be induced on the coils. If the movement of the armature be small, then each vibration will induce a weak pulse of current; if the amplitude of the vibration be greater, then the strength of the pulse of current will be proportionately greater. Lastly, if the movements of the armature be regular or irregular, then the form of the current pulses will be proportionately regular or irregular.

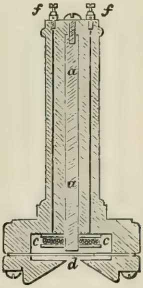
Imagine, then, a small iron armature attached to a tightly stretched membrane, and suppose the poles of an electro-magnet to be in close proximity to the armature, and let the electro-magnet be in circuit with a battery and the vibrating plate arrangement just described; then it is evident that, inasmuch as the magneto currents given out by the electro-magnet will be in exact accordance with the vibrations of the membrane and the armature attached to it, and also since the movements of the iron plate previously referred to will be in exact accordance with the currents passing through the electro-magnet to whose poles it is near, therefore sounds produced near the membrane, and setting the latter in

vibration, will induce currents in the electro-magnet near it, and these currents, in passing through the electro-magnet near whose poles is placed the iron plate, will cause the latter to vibrate in exact unison with the membrane, and thereby to reproduce the sound uttered near the latter both in pitch, intensity, and quality.

The first speaking telephone of Professor Bell was constructed on the foregoing principles. In the course of his experiments, however, it was found that the larger the armature on the membrane, the better were the results; and finally it was discovered that the best effects of all were obtained when the membrane was altogether dispensed with and a sheet of iron substituted in its place. It was also seen that the function of the battery in the apparatus was simply to produce magnetism in the cores of the electro-magnet, and that consequently the substitution of permanently magnetised cores would enable the battery to be done away with; and, further, it was found that both the transmitting and receiving portions of the apparatus might be made alike.

Fig. 446 shows in elevation and section the form which the in-

Fig. 446.



strument finally assumed, and which has been found to answer admirably in practice.

The instrument outwardly somewhat resembles the mouthpiece of a speaking tube. *d* is a diaphragm formed of thin sheet iron (a 'ferrotype' plate is found to answer well for this purpose). The centre of the surface of this plate is in close proximity to the pole of a permanent steel magnet, *a a*. A small bobbin, *c c*, of silk-covered copper wire of about No. 38 B.W.G. surrounds the pole of the magnet, the ends of the wire being led up to the terminals *f f*.

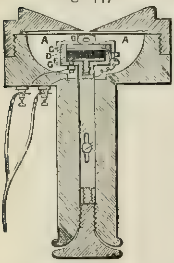
The articulation of the telephone, although rather faint and possessing a kind of metallic ring, is very clear, and conversation can be carried on with great facility by using the instrument in the same way as a speaking tube.

It is usual to employ a pair of telephones at each end of the line, so that one can be placed to each ear when receiving a communication.

A telephone transmitter based upon a novel principle has been invented by Mr. Edison. This gentleman made the discovery that properly prepared carbon possessed the remarkable property of altering its electrical resistance in a regular ratio, according to the amount of pressure to which it was subjected, and that a very slight pressure was required to make this change very sensible.

Acting on this principle, Mr. Edison constructed the telephone transmitter shown by Fig. 447. E is a disc of the prepared carbon; this is placed between two platinum plates, D and G, which are connected in circuit with a battery and a Bell telephone. A small piece of rubber, B, is attached to the centre of a metallic diaphragm, A A, and presses gently against an ivory piece, C, which is placed directly on the uppermost of the platinum plates. On speaking near the diaphragm, the latter vibrates, and the vibrations so produced, by exercising varying pressures on the carbon disc, cause corresponding variations in its resistance, and consequent corresponding variations in the current flowing from the battery; these variations of current, by acting on the diaphragm of the Bell telephone receiver, reproduce the sounds uttered. The best effect with the carbon telephone is obtained when the disc of carbon and the battery are in circuit with the primary wire of a small induction coil, the secondary wire being connected to the line.

Fig. 447.

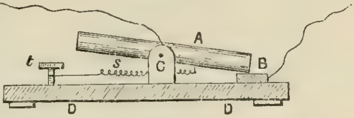


(295) **The Microphone.**—In the telephonic transmitter of Edison, as has been seen, the vibrating movements of a diaphragm exert varying pressures on a conducting substance, and thereby vary its resistance. Professor Hughes since made the discovery that sonorous vibrations might be caused directly to vary the resistance of various substances without the employment of a diaphragm, and that this could be done in the most simple manner. Thus if a small glass tube is filled with a metallic powder, the ends being stopped with corks, through which conducting wires are passed for a short distance, then on including this tube in the circuit of a Bell telephone and a small battery, sounds uttered near the tube are reproduced with surprising clearness in the telephone. If the tube be filled with small pieces of wood carbon whose pores are impregnated with mercury, the effect is still better; the slightest touch on the glass tube is heard distinctly on the telephone. A

portion of chain included in the circuit in the place of the glass tube transmitter was also found to be actively sensitive to any sound uttered near it.

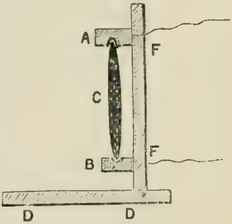
The most effective form of transmitter, or microphone, as it is called, devised by Professor Hughes is shown by Fig. 448. It consists of a small rod of willow carbon, A, about $1\frac{1}{2}$ inch long, impregnated with mercury by heating it red hot and plunging it in a bath of mercury; this rod turns on a small axle, C, and the end rests on a small block, B, also of the prepared carbon. The whole is mounted on a piece of wooden board, D D. Wires are connected to B, and to A through the medium of the bearing C. A small spring, *s*, adjustable with a finger-screw, *t*, is sometimes added for the purpose of enabling the pressure between the two pieces of carbon to be varied.

Fig. 448.



This apparatus, when included in the circuit of a Bell telephone and battery as with the other forms of transmitters, is extraordinarily sensitive; the slightest touch on the wooden board D D is heard most distinctly on the telephone, whilst the walk of an insect across the board is no less evident. Singing or speaking near the apparatus is heard very distinctly on the telephone, the articulation being very clear.

Fig. 449.



Another effective form of microphone is shown by Fig. 449. It consists of two small blocks of gas carbon, A and B, fixed to a vertical wooden support, F F, which is supported on a base, D D. Resting in hollows in A and B is a lozenge-shaped piece of carbon, C. Wires are connected to A and B, which are in circuit with the telephone and battery, as with the other forms of transmitters.

Other forms of the microphone have been devised, but none of them differ essentially from those described.

The cause of the phenomena in all cases is, no doubt, due to a variation in the resistance offered to the passage of the current at the point of contact of the pieces of carbon, this variation being caused by the vibratory movements imparted to the carbon.

Professor Hughes has also discovered that the microphone may be used as a receiving as well as a transmitting instrument. The receiving instrument is simply the form of microphone shown by

Fig. 448, mounted on a small drum-head or resonating disc, made of a tin cylinder closed at the top by a tightly stretched membrane. With this receiver, employing a battery of about six Daniell cells, the ticking of a watch placed on the stand of the microphonic transmitter may be distinctly heard. Articulate speech may even be heard, though imperfectly.

CHAPTER XXI.

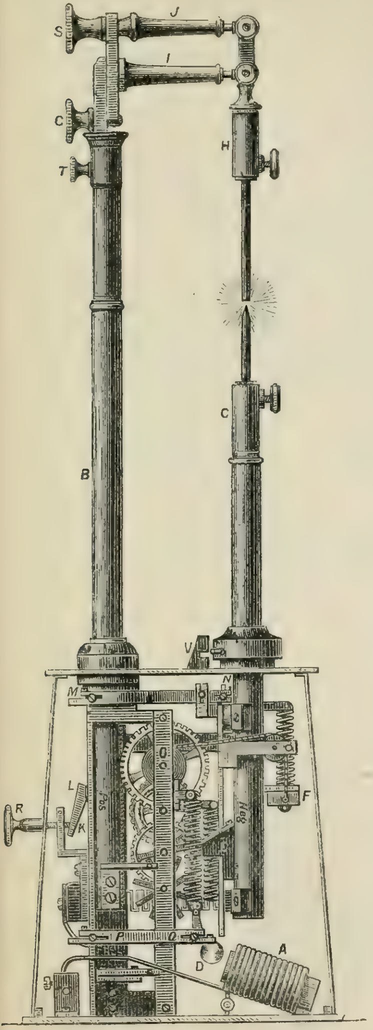
THE ELECTRIC LIGHT.

Electric Lamps—Serrin's—Siemens's—Rapieff's—Régnier's—Wallace's—Way's—Jablochkoff's Candle, Lamp, and Automatic Shunt—Subdivision of the Light.

The electric arc produced by a powerful current between two carbon points, after they have been brought into contact and then separated, has been described in § 130. The dazzling brilliancy of the light, first investigated by Davy with 2,000 cells early in the century, has long led philosophers and engineers to endeavour to utilise it for purposes of illumination. Foucault's ingenious attempt to compensate the unequal burning of the carbon points, as constructed by Duboscq, has been described (131), and has remained the principle of nearly every lamp that has been introduced since his day. Some mechanical arrangement is employed as a self-acting regulator for retaining the carbons at the proper distance apart to maintain the arc, and to bring them together automatically when the arc is broken. Of the numerous lamps constructed on this idea, Serrin's is, perhaps, the best known and the most used. It is shown by Fig. 450. The light itself is a fixed point, and is made so by two distinct though connected mechanisms. The upper carbon is attached to a rod T which slides within the tube B. This rod has on its lower extremity a rack which gears into a toothed wheel O, and propels it by its weight in falling. The lower carbon is fixed into a rod C that slides within the tube E. A chain is fixed to the lower extremity of this tube at F, which, passing over a pulley *f*, is attached to the toothed wheel O in such a way that as the rod T falls the rod C is raised just half the distance. Thus, as the two carbons burn away unequally, they are constantly approaching at the same rate, and therefore the arc remains at the same point. The current that maintains the arc passes through the electro-magnet A, which attracts the armature D. If from any

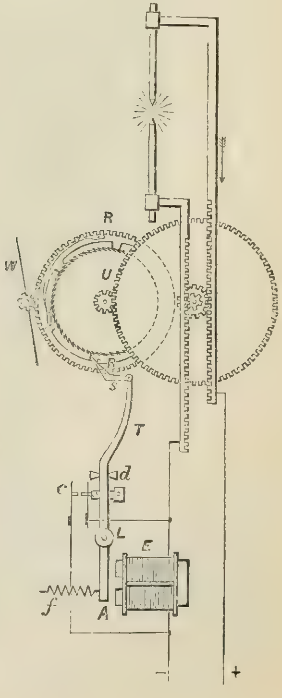
cause the arc goes out and the current ceases, the armature is pulled back by the antagonistic spring K, and in doing so it lifts up the rod C by means of the link motion M N P Q, and brings the two carbons in contact. The current is thus restored, the arc re-established, and the light renewed.

Fig. 450.



Siemens's lamp is somewhat similar. The approach of the carbons is

Fig. 451.

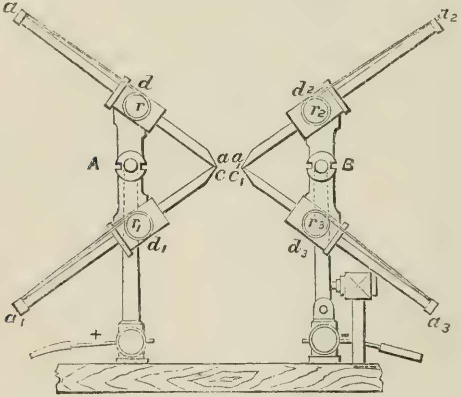


effected in a similar way, but they are kept apart not by the pull of the electro-magnet, but by a step-by-step action of the armature of the electro-magnet. When the current first passes through the circuit, the armature A is attracted, which short-circuits the electro-magnet at *c*. It is then withdrawn, and again attracted by the completion of the circuit. Thus a step-by-step motion is given to the armature, which, by the click *s*, propels a train of wheel-work *v*, forcing the carbons apart until the current is sufficiently weakened, so as no longer to attract the armature when the light burns steadily. Thus by the combined action of the weight of the top carbon in drawing the carbons together, and of the current in separating them when they approach too closely, a proper arc is automatically obtained.

Rapieff's Lamp.—The principle of this ingenious arrangement is shown by Fig. 452:—

Two sets of carbons a, c and a_1, c_1, which are set obliquely, meet with one another at their ends, as shown. These carbons are

Fig. 452.

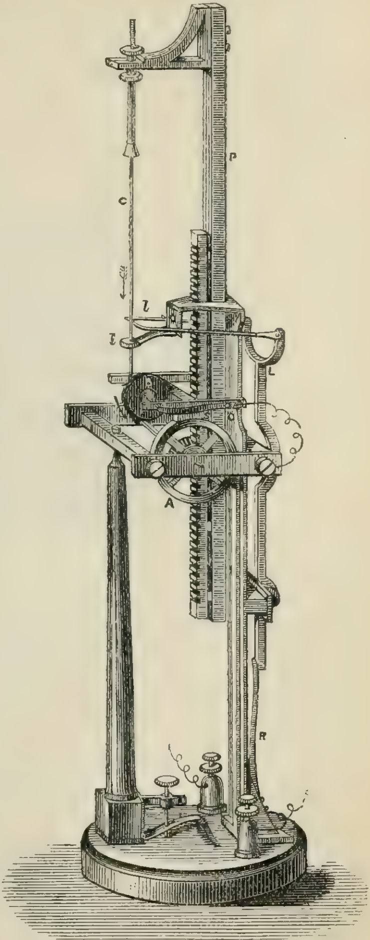


supported by and move longitudinally in tubes or slides d, d_1, d_2, d_3, fixed to the standards A and B. Springs or weights connected to the pulleys r, r_1, r_2, r_3 tend to press forward the carbons through the medium of cords attached to their ends a, a_1, a_2, a_3, so that the ends a, c and a_1, c_1 always remain in contact, however much they may be wasted by burning. Moreover, the locality of these points of contact always remains the same, and thus the distance between a, c and a_1, c_1 is always preserved constant.

By means of joints in the standards A and B the angle at which

the carbons are inclined to one another can be altered if necessary. The distance between the two sets of points can be varied by sliding one of the stands forwards or backwards.

Fig. 453.

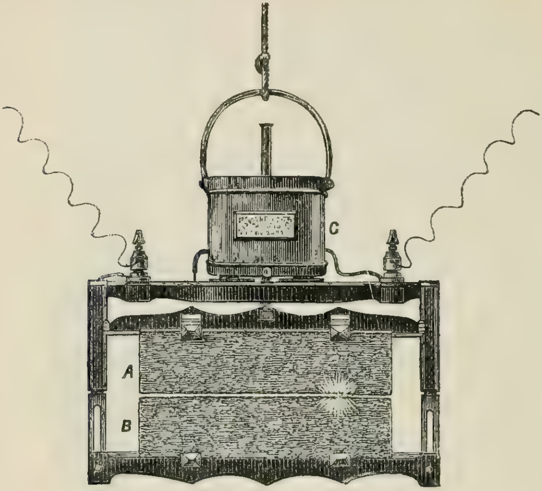


In cases where subdivision of light is required, and several lamps have to be put in one and the same circuit, it is absolutely necessary that some arrangement be provided which will prevent the interruption of the circuit should one of the lamps fail and cause a disconnection. In order to effect this object, M. Rapieff provides two paths for the current to flow through at each lamp, one through the carbon points, and the other through a circuit which is interrupted the moment the current flows between the carbon points, but which is completed again should the current fail between them.

Régnier's Lamp (Fig. 453).—In this the lower carbon is replaced by the disc B, which slowly rotates as its edge is consumed, while the upper carbon C falls by the weight of the rod P. An elastic contact-piece *l* presses against the carbon rod. The disc B is fixed to a lever centred at O, which has a break S upon it checking the rotation of the wheel A, and thus regulating the descent of the rod P.

The Wallace Lamp.—This is one of the latest novelties. Instead of carbon pencils, a carbon plate A is superposed above another B, the two being separated, when the arc is alight, by about one quarter of an inch through the attraction of the electro-

Fig. 454.



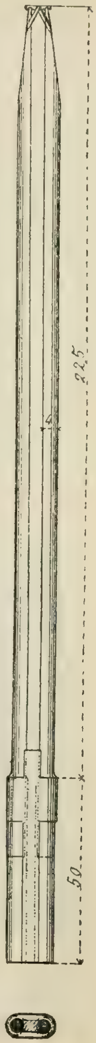
magnet C. As the arc burns away the carbon, it moves along the plate from one end to the other, and then back again. By this means a very continuous light is obtained, one, indeed, that is said to burn for 100 hours. When the light goes out, the armature falls, the carbon plates are brought into contact, the current is restored again, the plates separated, and the arc relit. Though the light is not steady, it is at least permanent, and it has thus solved one difficulty in electric lighting.

Way's Lamp.—This lamp was invented in 1856. The carbons were replaced by a fine stream of mercury issuing from a small funnel and received in an iron capsule also containing mercury.

The two poles of the electric generator were put into communication, one with the funnel, the other with the capsule, and there was produced between the successive globules of the discontinuous vein a series of voltaic arcs, and thus a regular lighting focus was obtained. The luminous liquid vein was placed in a glass chimney of limited diameter, so that this might become heated, and thus the condensation of the mercurial vapour upon the sides was prevented,

and, as the combustion was carried on out of contact with oxygen, the mercury was not oxidised.

Fig. 455.



Mr. Way modified this first arrangement, and obtained a better light by employing (1) two outflow electrodes instead of one, so that currents of mercury, each connected with one of the poles of the battery, falling from the two jets, are carried away by a pipe; (2) by making and breaking the electric circuit very rapidly by means of a small motor, worked by the battery and actuating a mercurial pump.

In spite of all precautions the apparatus allowed of the escape of very dangerous mercurial vapours, which finally killed the inventor. The light produced by this means was never very intense, and attained only a third of that given by the same electric current between two carbon points.

The Jablochkoff Candle.[1]—M. Jablochkoff has the merit of having dispensed with all machinery in regulating the distance between the carbon points. He places the two carbons side by side, but separated from each other by kaolin or plaster of Paris. The current used is alternating, and it thus causes the two carbons to burn at an equal pace. The heat of the arc fuses and volatilises the insulating substance, and it burns like the wick of a candle; hence its name. It is very extensively used in Paris, and is about to be employed in London.

The electric candle of M. Jablochkoff is represented in Fig. 455, the upper sketch being an elevation and the small sketch below it a cross section. It consists of two cylindrical pencils of compressed carbon, 8·865 inches (225 millimetres) long and 0·157 inch (4 millimetres) in diameter; these pencils are placed side by side about 3 millimetres (0·118 inch) apart, and are connected together mechanically, but insulated electrically by a layer of a substance which is insulating at ordinary temperatures, but which fuses with incandescence and becomes a conductor at the temperature of the electric arc. In his earlier experiments both glass and kaolin were

[1] We are indebted to that excellent scientific periodical *Engineering* for the description and illustrations of the Jablochkoff light.

used by M. Jablochkoff, but the substance employed in his system at the present moment is plaster of Paris. This substance gives to the light a slightly pinkish hue, and causes it to be more steady than the kaolin, which imparts a bluish tinge to the arc. The lower end of the pair of carbons or 'candle' so formed is embedded in a mass of composition for giving to it solidity, and a little metallic plate, for making electrical contact with its holder or 'candle-stick,' is attached to each pencil, there being one on each side of the candle. In order to establish the light, one of the pencils is placed in metallic connexion with one pole of the dynamo machine, and the other pencil with the other pole, and when the arc is once established at the top of the candle it will continue to be produced as long as the machine is at work and until the candle is consumed. In the earlier stage of the invention, whenever the light had to be started, it was necessary to hold a small piece of carbon for an instant against the top of the candle, so as to connect the two carbon 'wicks.' This little fragment of carbon instantly became incandescent under the influence of the electric current, and the arc was at once established.

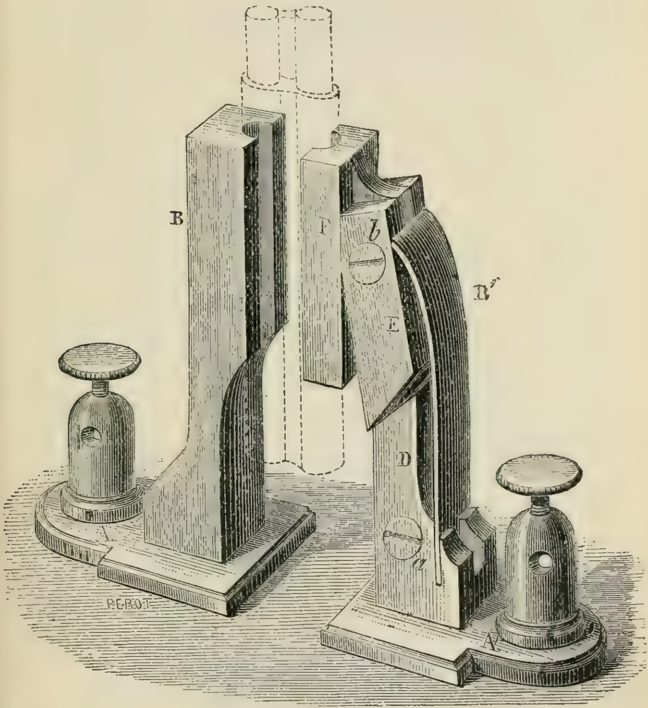
The next step in advance rendered this attendance unnecessary by the attachment to the top of each candle, by means of a little band of asbestos paper, of a small stick of carbon but one millimetre in diameter. With this contrivance it was only necessary to start the dynamo-electric machines, and all the candles in the circuit were simultaneously ignited, without requiring any attendance for that purpose. The substance used for this purpose under the present system is a mixture composed of powdered plumbago and gum, and a little piece of this compound is attached to the top of each candle in the process of manufacture. It is shown at A, Fig. 456, which represents the upper end of one of the candles, C D being the carbon pencils and B the insulating material between them. The essential principles involved in the Jablochkoff candle are the placing the carbons side by side, so as to form a two-wicked electric candle, and the employment of an insulating substance between them which gradually loses its resistance as high temperatures are reached. It is to this latter quality of the insulators employed that is due the success of the Jablochkoff system in spreading the electric current over a number of lights.

Fig. 456.

The arrangement by which the candles are held is very simple

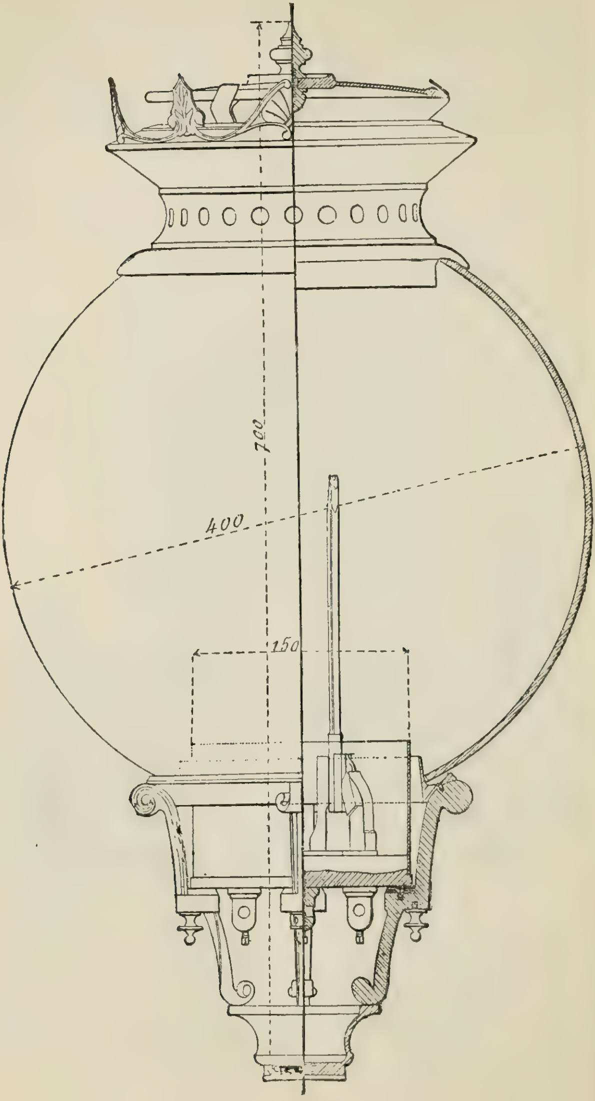
and ingenious. It consists (see Fig. 457) of a pair of brass jaws, B and F, insulated from one another, each having a semi-cylindrical vertical groove in its face to receive the candle, which in the figure is represented in dotted lines. The jaw B is rigidly fixed to the base-plate A, to which is attached the attachment screw connected with the positive electrode of the machine, while the

Fig. 457.



jaw F is jointed to the bracket D, which is attached to, and is in metallic connexion with, the attachment screw A′. By this jointed arrangement the clip can receive and hold firmly candles of sizes varying within certain limits, and by means of the spring B′ a firm pressure is maintained between the brass jaws and the metallic plates attached to the carbon pencils. The terminal screw A′ being

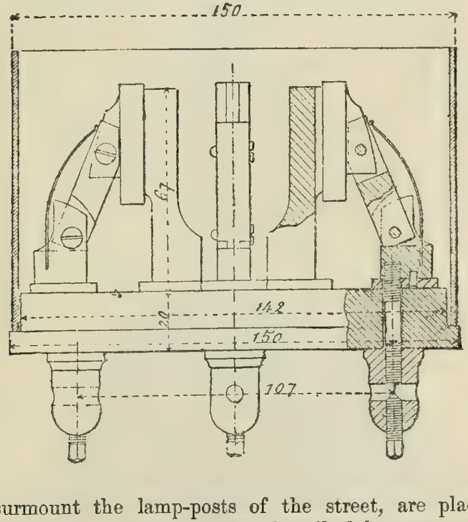
Fig. 458.



connected to the negative electrode of the machine, the circuit is completed as long as the arc continues to be produced. Instead of connecting the screw A′ direct to the machine, it may be connected to a second candle-holder, and that to a third, and so on in series; in fact, in the Avenue de l'Opéra, and in the other places in Paris illuminated by the Jablochkoff light, the lamps are arranged in groups, each group being illuminated by one circuit.

Fig. 458 represents one of the lanterns which are now installed on each side of the Avenue de l'Opéra. The portion of the figure to the left of the central line is an elevation of the lantern, and that to the right is a vertical section. In each of these lanterns

Fig. 459.



which surmount the lamp-posts of the street, are placed four candles, held in clips similar to that described, but arranged in the form of a cross round a common centre. Fig. 459 is a sectional elevation of the arrangement, and Fig. 460 is a plan. It is necessary to have four candles in order to carry on the illumination for the time required, as each candle lasts but an hour and a half. Only one candle is burning at one time in each lamp (except in the Place de l'Opéra, where two are employed for greater illumination), and when one candle is burning low the circuit is shunted from it to a new candle, until the four have been consumed, by which time the hour for extinguishing the lights has been reached.

The arrangement of candle-holders shown in Figs. 459 and 460 are

Fig. 460.

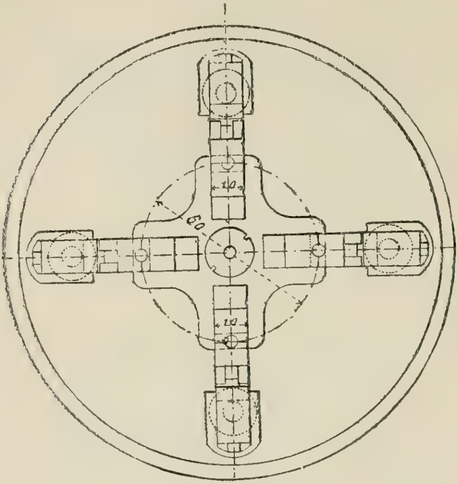
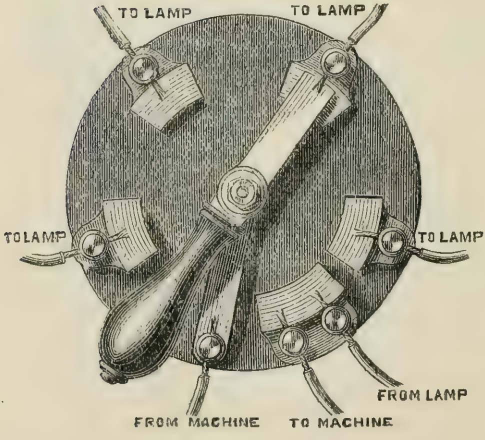


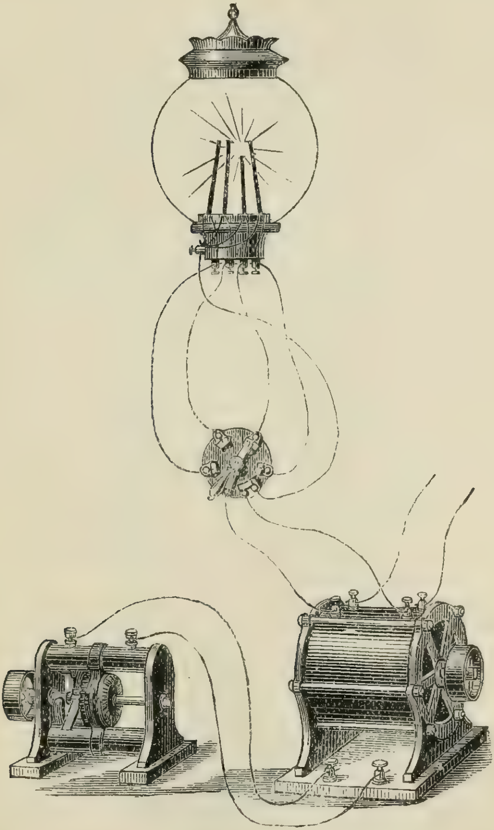
Fig. 461.



attached to a circular slab of white onyx, 6 inches in diameter,

which gives to the lantern a very handsome appearance both by day and night; and the whole is surrounded by a globe of opal glass $15\frac{3}{4}$ inches in diameter, which protects the candles from wind and weather, and by diffusing the light takes away all dazzling glare,

Fig. 462.



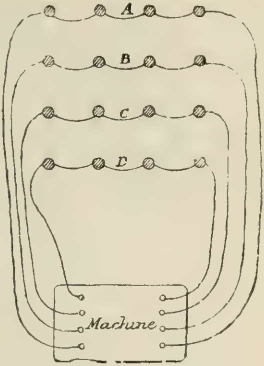
but there can be no doubt that the addition of a simple inexpensive optical apparatus, by which rays escaping vertically upwards could be directed where light is required, would greatly increase the effective power of the light, and would consequently make it more

economical. The opal globes, too, should be very much larger. The four fixed jaws are attached to a common central base-plate in connection with a terminal screw for making connection with what may be called the return wire of the circuit; the four spring jaws are insulated from one another by the onyx slab, and they are each fitted with an attachment screw, three of which are shown at the bottom of Fig. 459. To these screws are connected four conducting cables, which, passing down through the hollow shaft of the lamp-post, are connected to the similar attachment screws of the shunt fixed in the expanded pedestal of the lamp-post, and which is accessible by means of a door. One of these shunts is shown in Fig. 461. It consists of a circular disc of wood, upon which are fixed four brass contact-pieces, connected respectively to the four candles by the conducting cables above referred to; and a shunt lever, pointed at its centre, by which the current entering from the machine may be directed to any one of the four candles. Under the present system, and until the automatic shunt is installed, at intervals of about an hour and a half a man goes round, and opening the little doors in the pedestals, he moves the lever from one contact-piece to the next, and in so doing throws the stump of the old candle out of the circuit and a fresh candle in. In Fig. 461 the terminals marked 'to lamp' are connected to the four outside connection screws of the lantern, while that marked 'from lamp' is in connection by a fifth cable with the central plate in connection with the inner jaws of the candle-holders. The binding screws marked 'from machine' and 'to machine' are connected by underground cables with the lamp-posts on each side of it, which are included in the same group. The diagram (Fig. 462) will explain the connections between the lamp and the shunt, and between the shunt and the machine circuit.

For illuminating the Avenue and Place de l'Opéra at Paris there are three machines, each of which has four pairs of terminals, by which connections with four circuits may be made; and as each of these circuits actuates four lamps, it follows that each machine supplies the light to sixteen candles burning simultaneously, and the three machines together illuminate no less than forty-eight lamps. The circuits are arranged in groups of four lamps, each of which are joined together in series. The diagram (Fig. 463) will explain the method of joining up. The circuit from the first pair of terminals produces the light for the four lamps marked A, that from the second pair illuminates the group B, that from the third pair the group C, and that from the fourth pair of terminals renders incandescent the four candles marked D, and the same arrangement is adopted for each of the three machines.

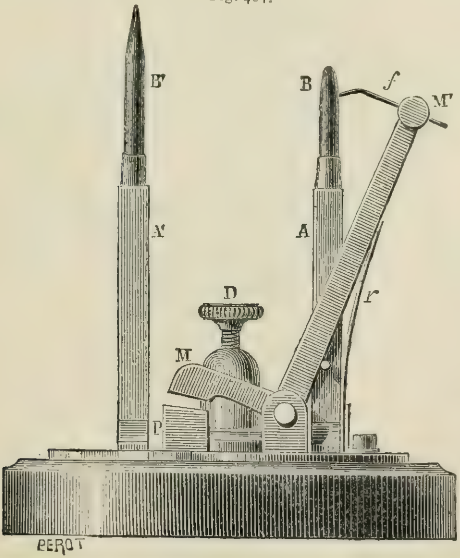
The conducting cables consist of seven tinned copper wires, 0·047 inch in diameter (about No. 18 B.W.G.), twisted into a cord and covered with several thicknesses of india-rubber wound on in the form of ribbon and united by india-rubber cement. In the Place and Avenue de l'Opéra and in other parts of Paris these cables are laid underground within earthenware drainage pipes, cemented together and supported at distances of about 18 inches by insulators, so as to keep them as nearly as possible in the axis of the piping.

Fig. 463.



In order to dispense with the services and the cost of an attendant going round from lamp to lamp and shunting the current from a candle nearly burnt out to a fresh one, the

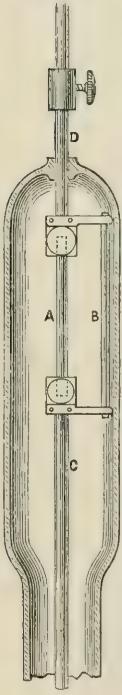
Fig. 464.



following simple arrangement is now adopted, and will soon be in-

stalled in all the currents of the Jablochkoff system:—This automatic shunt, to which we have alluded in our first article, is represented in elevation by Fig. 464. A and A′ represent two candle-holders, in which are placed two candles, B and B′. The current enters by the cable E and terminal D (Fig. 464), and leaves by the terminal D′ and cable E′, having traversed the candle A B or A′ B′, according as the bell-crank shunt-lever M M′ is lifted from its contact P, as shown in Fig. 464, or is resting against it. The natural tendency of this shunt lever is to close the circuit with the contact-piece P, and therefore to ignite the candle B′, for it is pressed in that direction by the spring *r*. It is, however, kept away from it by the platinum wire *f*, attached to the upper end of the lever M M′ resting against the insulating material of the candle B at a point in its length not far from where it is held in its holder A. As soon, therefore, as the candle B burns down to the point at which the wire rests against it, the latter, having no longer anything to keep back, is released, the lever flies over, making connection between M and P, and the fresh candle B′ is instantly and automatically thrown into the circuit, and this will continue to burn until a second lever, released in the same way, shunts it out of connection with the machine and places a third in the circuit.

Fig. 465.



The subdivision of the light has recently occupied the attention of inventors. Jablochkoff works four lamps simultaneously. Wallace has worked ten. Attempts have been made to do this on a much larger scale by raising platinum and iridium to incandescence, or to that temperature just below melting point. A soft and gentle light is thus obtained. But the result has not been commercially successful, though probably this is the direction in which ultimate success will be obtained.

As early as 1845 King, in London, tried to do this also with carbon. His lamp is shown by Fig. 465. C is a conductor, which rests in a bath of mercury, D, the other conductor being hermetically sealed into the glass tube, which is made a vacuum. The rod A, to be raised to incandescence, is fixed between two blocks joined by the porcelain bar B.

Lodyguine, of St. Petersburg, tried the same thing in 1874, and Konn, of the same place, in 1875. Another Russian—Bouliguine—more recently has followed the same idea, without much success as regards lighting

power, though all have solved the difficulty of the subdivision of the current.

The sources of electricity employed in generating currents to produce the light are almost invariably one or other of the forms of magneto-electric machinery described in Chapter XV.

It is now very largely used for lighthouse illumination, and is gradually being introduced for large workshops. One of the first firms to introduce it into England were Messrs. Head, Wrightson, and Co., of Stockton-on-Tees. They used Siemens's dynamo-electric machine, of $1\frac{1}{2}$ horse power (186), and lamp (Fig. 450), giving 1,000 candle power, fixed thirty feet from the ground, at a cost of one shilling per hour.

CHAPTER XXII.

MISCELLANEOUS PRACTICAL APPLICATIONS OF ELECTRICITY.

Electric Clocks: Bain's, Wheatstone's, Jones's, Ritchie's, Breguet's, Shepherd's, Cooke's—Chronoscopes—Chronographs—Electric Thermometers—Electric Target—Electric Log—Electric Break—Electric Boiler Feed—Electric Hydrostatimeter—Electric Engraving Machine—Electric Loom.

(296) **Electric Clocks.**—Electric clocks are coeval with telegraphs, and are worked by the same means. They are of two kinds—1st, those which are worked or propelled by the effects of the current; 2nd, those which are controlled or regulated by currents. Bain and Wheatstone each claimed to be the inventor of the electric clock of the first kind.

Bain's.—The mechanism of this ingenious instrument, which was exhibited in the spring of 1841 at the Polytechnic Institution, will be understood from Figs. 466 and 467.

B (Fig. 466) is a back-view of an ordinary clock with a pendulum vibrating seconds; C, a plate of ivory affixed to the frame of the clock, in the middle of which is inserted a slip of brass in connection with the positive pole of a battery. To the pendulum is attached a very light brass spring, F, in such a manner that every vibration of the pendulum brings the free end of the spring into contact with the strip of brass, thus completing the circuit, which is broken again as soon as the spring touches the ivory. A series of electric clocks may be connected by means of the wires

with this clock, and if a battery be included in the circuit, they will all go together.

Fig. 467 is a back-view of a corresponding clock on the same wire : *a* is an electro-magnet, and *b* its armature, suspended by a spring, pendulum-fashion ; *c* is a small screw, to regulate the distance of the armature from the electro-magnet. At the lower end of the armature is jointed a light click-lever, *d*, falling into the teeth of a ratchet-wheel, *e* ; *f* is a spring to keep the ratchet-wheel steady. When the pendulum of the clock sends an

Fig. 466.

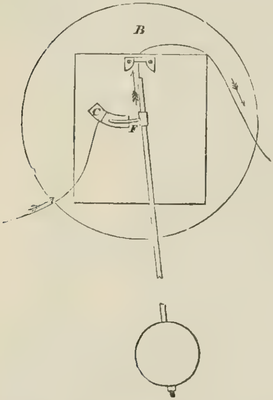
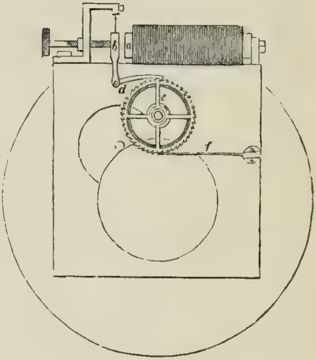


Fig. 467.



electric current through the conducting wire, the armature is attracted by the magnet, and the click lever *d* takes over one tooth of the ratchet-wheel; upon the current being arrested (by the spring F of the pendulum, leaving the slip of brass in the primary clock), the armature falls back into its former position, and causes the click-lever to draw the ratchet-wheel one tooth forward. The arbor of the ratchet-wheel carries the *seconds-hand*, which is thus taken forward one degree every second, corresponding to the vibration of the clock B. A pinion on the ratchet-arbor gives motion to other simple wheel-work, which carries the minute and hour hands.

Wheatstone's Electric Clock.—This instrument was exhibited and explained at the Royal Society, Nov. 25, 1840. In its construction, all the parts employed in a clock for maintaining and regulating the power are entirely dispensed with. It consists simply of a face with its second, minute, and hour hands, and of a train of wheels which communicate motion from the arbor of the seconds-hand to that of the hour-hand in the same manner as in an ordinary clock train ; a small electro-magnet is caused to act upon a peculiarly constructed wheel placed on the seconds-arbor in such a manner that whenever the temporary magnetism is either

produced or destroyed, the wheel, and consequently the seconds-hand, advance one-sixtieth part of its revolution. On the axis which carries the scape-wheel of the primary clock a small disc of brass is fixed, which is divided on its circumference into sixty equal parts; each alternate division is then cut out and filled with a piece of wood, so that the circumference consists of thirty regular alternations of wood and metal. An extremely light brass spring, which is screwed to a block of ivory or hard wood, and which has no connection with the metallic parts of the clock, rests by its free end on the circumference of the disc. A copper wire is fastened to the end of the spring, and proceeds to one end of the wire of the electro-magnet; while another wire attached to the clock frame is continued until it joins the other end of that of the same electro-magnet. A constant voltaic battery, consisting of a few elements of very small dimensions, is interposed in any part of the circuit. By this arrangement the circuit is periodically made and broken in consequence of the spring resting for one second on a metal division, and the next second on a wooden division. The circuit may be extended to any length, and any number of electro-magnetic instruments may be thus brought into sympathetic action with the standard clock.

Wheatstone subsequently, with the aid of Mr. Stroh, made many attempts to introduce a reliable electric clock, but he failed. He discarded the battery and introduced electro-magnetic currents developed in a coil of wire oscillating over the poles of permanent magnets. Each indicating clock was actuated by an astatic system of magnetic needles, kept in continued rotation by these magneto-electric currents. Thus the whole circuit remained unbroken, and the currents were alternately reversed without any making or breaking contact—the chief source of failure in the former systems.

Jones's[1] *Electric Clock.*—Clocks worked by electricity are usually either driven by the galvanic current or regulated by the release of an escapement. In these plans, if the battery gets out of order; if the communicating wire is broken or badly insulated; or if any of the contacts are defective, the clock stops altogether; and it is probably this serious defect which has hitherto limited an application of electricity which at first sight would appear to offer very considerable advantages.

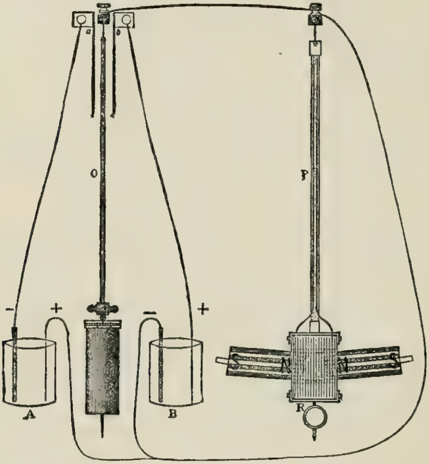
A few words will explain Jones's controlling system.

Each controlled clock is a complete clock in itself, requiring winding up as usual, and is regulated approximately to time,

[1] Mr. Jones was manager at the railway station at Chester.

having a pendulum P (Fig. 468), constructed similar to Bain's, vibrating over a bundle, or rather two bundles, of magnet-bars, SN–NS. The normal clock is furnished with slight springs A and B, one on each side of the pendulum-rod O, which are attached one to the copper terminal – of one battery A, and the other to the zinc terminal + of a second battery B, the other poles + and – of each battery passing by the line-wire or through the earth to one of the suspension-springs of the controlled pendulum P, thence down the rod and around the ball R to the second suspension-spring, and by the line-wire to the pendulum-rod of the normal clock.

Fig. 468.

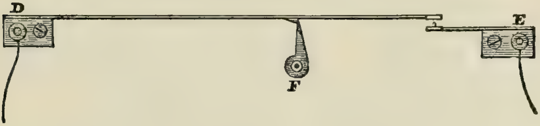


When the controlling pendulum swings and touches the one spring, a current of one kind is transmitted from the battery A along the wire, producing an attraction between the one pole of the magnet-bar and the wire coil R of the controlled pendulum P, the second battery B being meanwhile inactive, until the normal pendulum O in its reverse swing makes contact with it, and transmits through the spring *b* a current of the opposite kind to the controlled pendulum, producing, of course, an opposite result. Thus each second day and night an alternating current of positive and negative electricity is transmitted along the line-wire and through each pendulum, which most effectually secures the coincidence of beat of the controlled with the normal pendulum. Should

the controlled clocks incline to go too slow, these correcting currents drag them onwards; if too fast, then the currents retard the motion of their pendulums; and consequently perfect correspondence of time is obtained.

Ritchie, of Edinburgh, has carried out this system extensively. By his plan the different clocks report their accuracy by means of what is technically called dropt seconds. The Observatory clock, by its alternate contact with the springs on either side, sends out a current every beat. Inside the clock the wire passing to the pendulum-rod is cut and formed into a slight spring D (Fig. 469) resting on a fixed stud E at all times, except when a short arm F, on the seconds-wheel, raises the spring from the stud, and by

Fig. 469.



breaking the continuity of the wire prevents any current passing. This happens at the 30th second, as shown by the normal clock, and can be seen by introducing a galvanometer into any part of the line-wire.

In an exactly similar way another clock cuts the wire for two seconds, which are the 9th and 10th as shown by it. Two other clocks drop respectively the 25th and 35th second, and a fourth clock drops the 50th. This test forms the greatest security for the accuracy of the clocks.

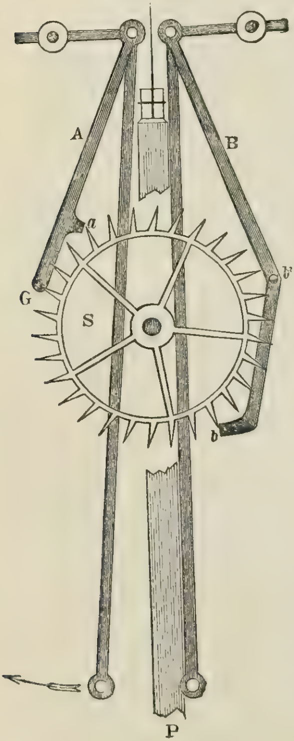
Ritchie has also introduced a sympathetic clock which requires no winding up, and is kept in motion by a very small amount of battery power, with the greatest certainty of coincidence. The name electro-sympathetic clock has been chosen to distinguish it from the purely electric clock. Each clock is no doubt really propelled by electricity, but the currents or waves are transmitted by a normal clock through the different pendulums connected with it, which are thus caused to vibrate in coincidence or sympathy with the governing clock.

Unlike former companion clocks, this is supplied with its own pendulum, acted on and entirely maintained in motion by the currents of electricity transmitted by the normal clock. The action is the same as that in the controlled pendulum, but the impulse is wholly obtained from electricity and not from the clock-work. To enable the pendulum thus kept in vibration to carry

forward the wheel-work, an escapement or propelment has been introduced, which gives to the seconds-hand an instantaneous motion like that of a dead-beat 'scapement, and so locks the wheel that no force whatever can carry forward the wheel beyond the stop, and no power less than the weight of the gravity-arm will drive the wheel-work backwards. Where great exposure to wind is experienced a light catch is added, which falling into each tooth effectually prevents its being turned backwards by any force whatever.

Fig. 470 represents a scape-wheel S, with 30 teeth acted on by two gravity-arms A and B, one on each side. The pendulum P is supposed to have completed its vibration to the right hand, and is returning to the left in the direction of the arrow. The right-hand arm B is just resting on the tooth, pressing it by its weight in the forward direction. The tooth, however, resting on the arc *a* of the left-hand pallet A, prevents its motion until the pendulum has advanced and raised by means of the crutch lever the arc or stop *a* out of the tooth, when the wheel is carried forward until the tooth rests on the arc or stop b^2 of the right-hand pallet B, against which it is locked by the weight of the arm till the pendulum in its return vibration relieves it in like manner, and allows the left-hand arm to force forward the wheel, and so on.

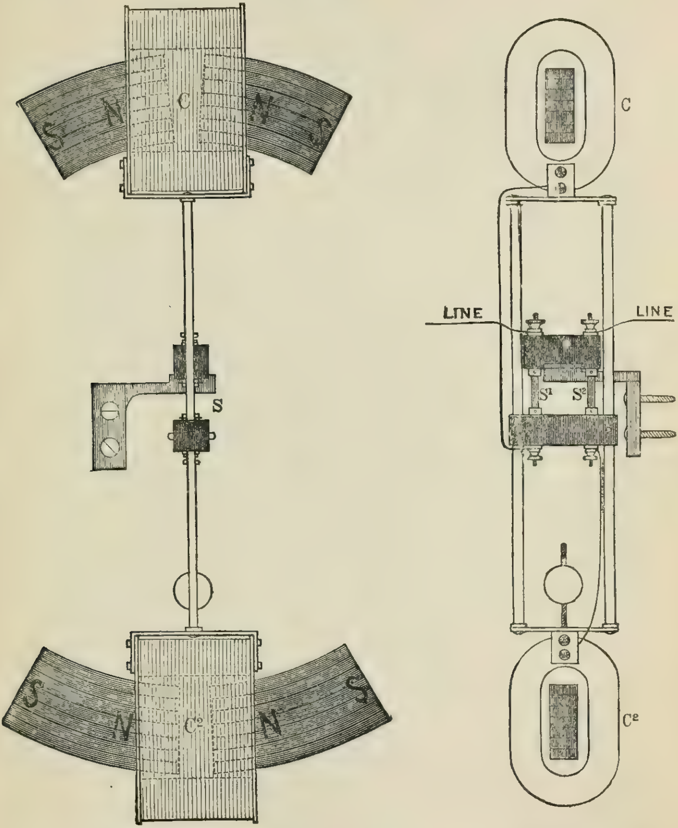
Fig. 470.



Another and much more powerful arrangement is obtained by loading a simple pendulum above its point of suspension. By this means a pendulum can be constructed to vibrate within the diameter of its own dial at any rate desired. In practice the balance-weight above the suspension is a coil of wire vibrating over or around bars of magnets. Fig. 471 represents such an

arrangement, C and C^2 being coils of wire one above and the other below the suspension-springs S^1 and S^2, and vibrating freely over

Fig. 471.



the clusters of magnetic bars N S. The currents entering by one suspension-spring pass through the one coil to the centre, thence by the rods to the centre of the other, after traversing which they pass off by the second spring, thereby doubling the electromotive force. The pendulum being maintained in motion by the transmitted currents, is applied to work the 'scapement (Fig. 470).

Breguet's Electric Clock.—Instead of correcting all the secondary or controlled clocks once a second, or once at every beat of the pendulum, M. Breguet corrects them only once or twice every twelve hours, by bringing the minute-hand exactly to the hour point. This is done in the simplest manner, by a little train of wheels driven from a barrel-spring, and set free by an electro-magnetic detent at the moment of correction; two small cams, one on each side of a projection connected with the minute-hand, are turned once round by this train of wheels; if the minute-hand be behind its time, one of these cams moves it on; if it be before its time, the other cam moves it back. This method is simple and effective where no extreme accuracy is required between the long intervals of correction. It, moreover, avoids the difficulty of making good contacts from the pendulum of the standard clock without some injury to its time-keeping qualities, a danger which Jones's method does not provide for. Barraud and Lund have introduced a somewhat similar system very extensively in London.

Shepherd's Electro-Magnetic Clock.—In this apparatus, which was a prominent object in the International Exhibition of 1851, the pendulum is so arranged as to make and break an electric circuit, and, consequently, to make and unmake a horseshoe magnet at each vibration. Each time that a magnet is made, it attracts an armature which lifts certain levers; one of these raises a weighted lever, and causes it to be held up by a detent or latch; the magnet is then unmade in consequence of the pendulum breaking the circuit, and the armature is released, when the pendulum lifts the latch and allows the weighted lever to fall, which, in falling, strikes the pendulum so as to give it an adequate impulse; then the circuit is again completed, the armature attracted, the levers moved, and the weight raised and held up by a detent; another vibration breaks the circuit and raises the armature, the pendulum then raises the detent, the weight falls, and in falling its arm strikes the pendulum and gives it an impulse, and so on.

But the pendulum at each vibration not only makes and breaks the electric circuit of the battery, which maintains its own action, but also, and simultaneously, that of a second battery, the duty of which is to make and unmake the electro-magnets belonging exclusively to the clock or clocks which are upon this circuit. These electro-magnets act upon the extremes of one or more horizontal bar-magnets, so as alternately to attract and repel their opposed poles; on the axis of these bar-magnets are the pallets by the alternating motions of which to the right and left the ratchet-wheel is propelled onwards at the rate of a tooth each second;

and the axis of the ratchet-wheel carries the pinion which moves the other wheels of the clock.

The circuit of the battery connected with the striking part of the clock is only completed once in an hour, and is connected with an electro-magnet so arranged as, by means of a proper lever, to pull the ratchet-wheel attached to the notched striking-wheel one tooth forward every two seconds, and each tooth is accompanied by a blow on the electro-magnetic bell. The number of blows depends upon the notched wheel, the spaces on the circumference of which are adapted to the number to be struck, and when this is complete a lever falls into the notch, and so doing, cuts off the electric current, which is not re-established through the striking electro-magnet till the next hour, when a peg upon the hour-wheel pushes the striking lever forward so as to cause it to be depressed by a similar peg upon the minute-wheel.

Cooke & Son's System of Electrically Controlled Clocks, as carried out by them in the telegraph gallery of the General Post Office, London, consists essentially of Jones's principle, with improvements of their own in mechanical details, and also in the fact that the clocks themselves, irrespective of the control, are excellent time-keepers, and will continue to go accurately should the electric current be at any time interrupted. A polarised relay is used for sending alternate positive and negative currents, in order that the standard clock (which works the relay) may not have the contacts burnt or oxidised by the larger spark which results when the current is sent direct through the whole of the clock pendulum-bobs. Twenty-one clocks in the gallery are thus accurately controlled by the same current (from four large-sized Daniell's cells), sent at the end of each oscillation of the standard pendulum; and the system is equally applicable to public clocks in various parts of a town or on a railway.

Another electric clock, by the same makers on a different principle, is also working in the same gallery. The dial of this clock is 6 feet in diameter, and the wheel-work connected with the hands is driven by a rod about 45 feet long, with two or three bends at right angles, which are passed by means of bevel-wheels.

The motor for driving this rod and the dial-hands is placed in a convenient position for inspection, and is of novel construction, the original design for which was made by Mr. E. Cox Walker, electrician to the Messrs. Cooke.

It may be generally described as consisting of two pairs of electro-magnets, each about 3 inches long, placed opposite to each other longitudinally on a flat plate of metal; a permanent magnet,

of the horseshoe form, being suspended between them, from the top of which an arm rises, carrying at its upper end a double ratchet, by means of which motion is communicated to a ratchet-wheel and the other necessary wheel-work. The chief advantages of this arrangement are that the usual counteracting spring for drawing the armature away from the electro-magnets at each beat is entirely dispensed with, and the permanent vibrating-magnet is substituted, and its magnetism utilised by reversing the current at each beat of the standard clock, thus causing it to be alternately attracted and repelled by each pair of electro-magnets. Its magnetism also holds it against one or other pair of electro-magnets during the time there is no current passing, thus acting as a check and steadier to the wheel-work until it is again moved by the passage of a current through the coils. It will also be seen that this arrangement requires only a very weak current to actuate it, as the magnetism of the permanent vibrating-magnet may be made sufficiently strong to do the work itself, the current through the electro-magnets being merely strong enongh to change their polarity. The working of the clock is very reliable, and we believe the principle capable of wide application for other purposes. The motor-works are covered by a glass case, and present a very neat appearance. Smaller clocks on this principle to hang on a wall, with the works all contained within a case of the ordinary office size, are also made by this firm.

(297) **Chronoscopes.**—These are instruments which are used for the measurement of very short intervals of time; they are employed principally for determining the velocity of projectiles and the value of gunpowders.

Wheatstone's plan for determining the velocity of a ball was this:—

Two screens, made each of a continuous wire led backwards and forwards across a frame, are placed in the path of the ball at a known distance apart. The wire of each screen forms part of two complete circuits communicating with the instrument. When the wires are successively broken by the projectile, the successive interruptions of the two currents are registered by electrical means on some apparatus, part of which moves with a known velocity.

It is not necessary that the two circuits should be distinct throughout their whole length; the rupture of the circuit containing the first screen by the very cessation of the current through it is easily made by electro-magnetic apparatus to establish a current through a circuit containing both the second screen and part of the first circuit. By these very simple contrivances, the

ball, as it successively breaks two circuits, sends, as it were, two signals by stopping two currents at the very instant that it passes through two points of the trajectory ; but it is by no means equally easy to *register* the instants at which these signals are sent. The time elapsing between them must be measured by reference to some continuous movement, of which the speed is accurately known, and it is very difficult to produce such a movement. Clockwork governed by an escapement can give only a step-by-step or intermittent motion; and no frictional governor hitherto used can be depended on to produce perfect regularity. A second difficulty arises from the fact that no electro-magnetic effect is absolutely instantaneous, and that especially the effect on soft-iron cores, such as are frequently used in recording apparatus, are extremely uncertain or variable, so that an electro-magnet cannot be depended upon to release or attract an armature at *constant* intervals after a given current is stopped. No doubt if every circumstance attending every experiment could be maintained rigorously the same, the electro-magnet would act constantly in one way, but in practice this cannot be effected. The use of Bain's chemical recorder to a certain extent remedies this defect.

A chronoscope, known as Navez's pendulum, is extensively used both abroad and in this country. It records time by marking an interval of the swing of a pendulum, or by measuring the arc described by the bob of the pendulum during the period to be measured. The unknown velocity of a projectile is referred directly to the known velocity of a pendulum.

A chronoscope which registers, by means of an induction spark, produced in a secondary circuit by the rupture of the primary, on the principle introduced by Schultze, was exhibited at the International Exhibition of 1862 by M. Hardy (Paris).

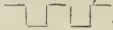
It consists of: 1. A fixed brass cylinder, one metre in circumference, round which a band of prepared paper can be firmly stretched. 2. An axial arm of steel, bearing a platinum point which revolves, describing a circle concentric with and close to the cylindrical surface of the paper. This arm is driven by clockwork. 3. A pendulum revolving round a prolongation of the axis of the cylinder, and driven by the axial arm, which presses against the lower end of the rod. This pendulum is intended to produce uniformity in the movement of the clockwork. 4. An induction coil with primary and secondary circuits. One end of the secondary circuit is in connection with the point of the axial arm, and the other with the large brass cylinder on which the paper is stretched. The primary circuit is connected with a screen, used as a target, and a current is allowed to circulate through it. The rupture of the screen, by interrupting the primary current, determines a spark in the secondary wire, registering the instant of the interruption by burning a small hole in the paper. By the

armatures of a series of electro-magnets, the primary circuits can be re-established through a succession of wires and screens, giving a series of observations. Each interruption of the primary circuit is said to last about one two-hundredth of a second.

Pouillet invented a chronoscope which depended upon the measurement of currents of very short duration by the magnitude of deflection given to a galvanometer.

Noble's chronoscope is used for measuring the velocity of the shot during its passage through the gun itself. The ball presses upon a series of discs which, in moving, break or make electric connections, which are recorded on Schultze's principle on a rapidly rotating disc having a known rate.

(298) **Chronographs.**—Instruments to which this name has been given are constructed for the purpose of *recording* the time at which a certain phenomenon occurs by means of electricity. They have been used for determining the difference of longitude between two places. The following description of an excellent apparatus exhibited at the International Exhibition of 1862 by M. Krille (Denmark) is taken from the *Jurors' Report*, and gives a good idea of the principle :—

A cylinder, covered with blackened paper, driven by clockwork, and regulated by a conical pendulum, revolves at a sensibly uniform speed. Two diamond points on the end of two levers are pressed against the cylinder as it revolves, and mark two fine white lines on the blackened surface. These levers are carried on a sort of car, to which a slow motion of translation is given parallel to the axis of the cylinder, so that the lines marked are helical and continuous. The levers are, moreover, connected with the armatures of two separate electro-magnets, also carried on the car. These armatures by their motion can produce a slight independent movement of translation on the diamond points along the surface of the cylinder. One of these electro-magnets is worked by contacts from a standard clock, so contrived as to produce a broken line equally divided, thus,  . The instant of the change of contact is thus singularly well and sharply defined. The second electro-magnet is worked by the observer with a key, and produces a little nipple, fixing the instant of observation by its position on the cylinder relatively to the broken or 'second' line. So far the arrangements, although extremely good, can hardly be called novel. The manner of observing the contacts from the standard pendulum is not only excellent but quite novel. Two short vertical glass tubes, placed side by side, have each near their lower end a small horizontal branch, the two open ends of which are placed in very close proximity opposite each other. The two larger tubes are partly filled with mercury, which flows through the two horizonal branches, until the two streams join in the open space between them. This space is, however, so small, that capillary attraction prevents the mercury from falling down, so that it is entirely retained inside the tubes, with the exception of this one short, exposed, and apparently unsupported drop hanging between the two branches. A very

thin sheet of mica is carried by an arm on the pendulum, so placed, that at each beat the mica-sheet descends between the ends of the two little branch tubes separating the mercury in the two reservoirs, and breaking all electrical communications between them. At the return of the pendulum, the mica-sheet is withdrawn, and the mercury at the two sides joins as before, making an electrical connection. The action of this admirable make and break arrangement seems all that could be desired ; the mercury is not spilt, as might be expected, and the contact appears to be made with perfect certainty and regularity. The friction must be almost nothing ; and if, as appears probable, the oxide formed by each spark is removed by the mica-plate in its descent, this plan might be very advantageously applied to all electric clocks and galvanometer relays.

Very many chronographs have been introduced by Breguet, Martin de Brettes, Gloesener, Siemens, Lissajous, Marcel Deprez, Marey, Hipp, Cornu, and Boulengé. In the last a weight falls freely in a vertical direction, and the intervals of time are measured off upon a scale. Hughes's type printer (261) makes an excellent chronograph.

(299) **Electric Thermometers.**—An instrument which may be used for determining the temperature at different depths in the sea, and for other similar purposes, was shown at the International Exhibition of 1862 by Siemens, Halske, and Co. It is called an electric-resistance thermometer, the change of resistance which metals undergo with a change of temperature, being made use of to indicate the temperature of the metal.

Two perfectly similar coils of insulated wire are enclosed in two hermetically-sealed copper cases. One is placed on the spot of which the temperature is required and the other in a bath of water. The temperature of the bath is altered until the resistance of the two coils is exactly equal, an equality which can readily be tested by a resistance galvanometer. The temperature of the bath will then clearly be equal to that of the spot where the first resistance coil is placed. The connections are made with very thick copper wire, so that their resistance shall have little or no influence on the result. The wires are coiled on an open copper cylinder of considerable diameter and length, so as to expose a large surface to the air or water in which they are placed. They in consequence take the temperature of the surrounding medium with great rapidity.

An electric self-registering thermometer, which is an application of Breguet's metallic thermometer, was also exhibited by the Telegraphen-Werkstätte of Berne (Switzerland). In this instrument the registering-paper is marked by the steel point of an index, carried by the outer end of a spiral formed of two metal strips (brass and steel) soldered together, the inner end of the spiral being fastened to a brass standard. The paper, a wide strip about 140 yards in length, is unrolled and passed under the steel point by two brass rollers, one of which is connected with a ratchet-wheel.

The paper is marked by an electro-magnet and armature; a momentary voltaic current is sent round the magnet at fixed intervals by a clock with suitable contacts. A lever fixed to the armature strikes down the end of the index at the moment when the current passes, and so prints a dot on the paper; when the current ceases, a paul fixed to the armature moves the ratchet-wheel one tooth forward, carrying the paper along with it. Two millimetres on the paper are equivalent to one degree centigrade. A little fixed wheel impresses a straight line in the centre of the strip of paper, from which the deviations of the curves formed by the dots can be measured.

(300) **Hemming's Electric Target.**—The target is divided into any number of sections required, and behind each section a little ball or hammer is hung, touching the plate, or a bolt rigidly connected with it. The plates forming each section are separately supported, so that when one is struck or shaken the others do not move. When any plate is struck, its ball or hammer flies back under the influence of the vibration, and for a short time completes a circuit which includes a wire leading to the firing station, a battery and an indicator or receiving instrument of some kind. Each plate has a separate conducting wire and indicating needle. The conducting wires are generally small copper wires insulated with india-rubber or gutta-percha, and twisted into some form of cable. These targets have been practically tested, and are found to answer.

(301) **The Electric Log.**—In this instrument, invented by Siemens, Halske, and Co., electricity is used to convey a signal to a step-by-step propelment or escapement inside the ship, from an ordinary Massey's patent log, at say every hundred turns of the vane, or at any other given fraction of a knot. An insulated wire is led from the ship to a train of wheelwork contained in an air-tight case, and driven by the vane of the log. This wheelwork makes the contact required at regular intervals, and these are marked by the index of the step-by-step instrument on board the ship. The log, therefore, need never be drawn in to be consulted, and the captain can at any time observe the speed of the ship.

(302) **Electric Break for Railway Trains.**—In this instrument, which is the invention of M. Achard (Paris), the electric current is not directly employed to produce the friction or retarding force, but the required power is obtained from the momentum of the train itself by letting a cam on one of the axles of each carriage work a paul, which turns a second shaft round by means of a ratchet-wheel upon it. This second shaft, by winding up a chain, pulls the friction-blocks against the rim of the carriage-wheels until,

by the stoppage of the axle, further action is prevented. Electricity only comes into play in so far as it is used first to determine the moment at which the paul shall begin to act; and secondly, to release the chain and so take off the break at the moment required. The first object is very simply attained. The paul is on one end of a lever, rocking freely on the ratchet-shaft. A prolongation of the other end of this lever is pressed by a spring against the cam on the axle. When the axle revolves, this spring keeps the lever against the excentric surface of the cam, and so rocks the lever and works the ratchet by the paul; a soft-iron armature is attached to the other end of the lever, which, as the lever rocks, slides backwards and forwards over the pole of an electro-magnet. The cam always pushes this slide back to its furthest limit in spite of any attraction of the magnet, even when a current is circulating round the coils; but when the cam recedes, the spring is not strong enough, while the current circulates, to pull the slide forward again, and it consequently remains motionless at the farthest point, so that the paul is no longer moved. A current passing round the electro-magnet thus prevents the break from being applied, or stops its further application; but the moment the current is interrupted, the spring works one end of the lever, pulling the slide forwards. The paul takes up successive teeth of the ratchet, and the break is applied with more and more force until the wheel is stopped.

The break is released by means of a second system of electro-magnets. The ratchet-wheel is not rigidly fixed to the shaft on which the break-chain is wound, but is connected with it by what may be called an electro-magnetic friction clutch. The flat poles of a number of electro-magnets fixed to and round the shaft come against the flat faces of a disc of iron attached to the ratchet-wheel. When a current is established round these electro-magnets, the disc adheres very tightly to them, and this is the case when the ratchet is used to put on the break, but the moment the current is interrupted in this second circuit, there is no force to hold up the break-blocks, which fall back from the wheels by their own weight, turning the shaft round, and unwinding the chain. Thus there are two circuits, which may be called the paul circuit and the clutch circuit. Nominally the current is established through both: if the first be interrupted, the break is put on either slightly, if the interruption last but a little while, or so strongly as to stop the wheel if the interruption continues; a short interruption in the second circuit again takes off the break. The same circuits may be employed for all the carriages, or the trains might be divided into short sections, each with a separate pair of circuits. The

wires of the paul circuit might be so placed, that passengers, in case of great danger, might cut them, and so apply the breaks. Many alterations and improvements have been made in this apparatus, but it has only been partially employed.

(303) **The Electric Self-acting Boiler Feed.**—This is also the invention of M. Achard, and was shown by him at the International Exhibition of 1862. A voltaic current is employed simply to stop or hold an armature. When the armature is loose, one of two pauls, constantly worked from the engine, turns a segmental ratchet, opening the feed-cock; but when the armature is held by the passing of a current through an electro-magnet, one paul is thrown out of gear, and the second paul into gear, working a second segmental ratchet which shuts the cock. When the cock is either fully open or fully shut, the paul in gear works in a blank space. The connections are made or broken by a float, mechanically connected with a commutator outside the boiler; if the circuit fail at any point, or if the battery become too weak, the worst that can happen is, that the armature would be relieved permanently, so that the boiler would get filled with water. Moreover, M. Achard uses a second armature, worked by thə same current, to ring a bell when the current is interrupted, in which case it rises and falls with an oscillating lever driven by the engine, and at each fall causes one beat of the bell. When the current is re-established, this armature is held up out of the way of the oscillating lever, and the bell stops ringing. This current is interrupted by the float when the boiler is too full or too empty. The bell, in either case, acts as an alarum, and it also draws attention to any accident, in consequence of which the connecting wires may have been broken or the battery become too weak.

This electrical apparatus seems as certain in its action as any mechanical construction; indeed, if a failure can possibly occur in any part without being at once discovered, it would be in the float, which might possibly stick instead of following the surface of the water. This apparatus has been successfully applied in France.

(304) **Electric Hydrostatimeter.**—This instrument, designed to show the level of water in a cistern by an index placed in any required position at a distance from the cistern, is the invention of MM. Mouilleron and Vinay. An electric circuit is made and broken by a float which sends positive currents at certain intervals as it rises, and negative currents at the same intervals while falling. The positive currents move the index of a step-by-step dial instrument in one direction, and the negative currents move the index in the opposite direction. The receiving apparatus

is very simple: two polarised electro-magnets, on Siemens's system (258), are so arranged that the armature of one works a ratchet-wheel in one direction, while the armature of the other works a similar ratchet-wheel on the same axle in an opposite direction; the two coils are both on one circuit, but the positive current alone moves one armature, and the negative current the other; the opposite currents simply press the motionless armatures harder against their stops—a position in which their pallets are clear of the ratchet-wheels. The ratchet is prevented from turning when the armature pallets are clear of them, by a little spring friction pallet.

The transmitting part of the *hydrostatimeter* is somewhat complicated. As long as the float continues to rise, it sends at definite intervals of, say, three inches momentary positive currents; when nearly stationary, it may oscillate up and down, sometimes two inches lower, and sometimes two inches higher than the level at which the last current was sent, without sending any current; it must fall or rise fully three inches after sending a given current before it sends any fresh current. Moreover, when it has *risen* three inches it will always send currents of opposite name to those sent after a *fall* of three inches.

(305) **Electric Engraving Machine.**—A machine for engraving the cylinders of copper or brass employed in printing woven fabrics and paper hangings, an invention of French origin, has been introduced in some places. The voltaic current is used to determine, by means of electro-magnets, the slight simultaneous advance or withdrawal of any number of engraving diamond points to or from the varnished surface of the copper rollers to be engraved, according to the position of a corresponding metal contact point on the nonconducting surface of a prepared pattern. The pattern and cylinder to be engraved are moved mechanically in concert, and the proportion of their relative movements can be varied by mechanical adjustment. The engraving points have a slight vibrating motion given to them, which scratches off the varnish whenever brought into contact with it, and produces a series of fine zigzag lines, which facilitate the retention of the pasty colouring matter used. The prepared pattern determines the moments at which this contact occurs; and the concert between the movements of the pattern and the roller produces a similar agreement between the pattern and the figures engraved, which may clearly be made larger or smaller than the pattern in any desired proportion and in any required number. The copper when exposed is afterwards etched by an acid bath.

(306) **Electric Loom.**—This extremely ingenious contrivance,

in which the usual Jacquard cards are replaced by an electrical arrangement, worked by a pattern prepared in tinfoil with insulating varnish, is the invention of Cav. G. Bonelli, of Turin.

A simple metal plate, perforated with holes, each of which is provided with a kind of piston, successively plays the part of each successive paper card in the usual arrangement. The pistons fill up every hole that is not required, but are withdrawn by electro-magnets from those holes which require at each beat of the loom to be kept open. This is effected as follows:—

A sort of metal comb, each tooth of which is the terminal of a separate insulated conducting wire, rests on the prepared pattern. Whenever a tooth touches the tinfoil, a circuit is completed through its conducting wire · but where a tooth rests on the varnish, the circuit is broken. Each conducting wire includes in its circuit an electro-magnet. The pistons already spoken of are each composed of a small soft-iron shank, and brass button shaped head, and are all held horizontally in a frame, one opposite each electro-magnet. In one position of this frame, the heads of these pistons project through the openings of the metal card or perforated plate; the diameter of each pole is a little larger than the head of the corresponding piston, each piston being exactly in the centre of its corresponding pole. In this same position all the soft-iron shanks touch the poles of the corresponding magnets, and the metal comb rests on the prepared pattern.

A certain number of the electro-magnets corresponding to the uncovered portions of the tinfoil, are therefore active and attract the shanks, but the others exert no attraction. The frame with the pistons is now pulled forward away from the magnets; those pistons which are opposite the active magnets are held back, sliding in their frame, so that their button-heads pass behind the perforated plate; but the other pistons come forward with the frame leaving the magnets. The perforated plate then drops a little way, and by this simple contrivance all those piston-heads that were in front of the plate are retained there, whatever pressure comes against them, for they are now excentric from the poles. The plate in this condition presents a perfect analogy with the common prepared card. A certain number of holes corresponding to the metallic part of the pattern are vacant; the rest of the holes are blocked up, and present an unbroken surface by which the proper hooks of the Jacquard loom are acted on during one stroke. The perforated plate is then brought back to the position first described, the prepared pattern is moved on a little step, and the same process repeated.

When shuttles with several different colours are to be used, the pattern is subdivided into insulated portions corresponding to the separate colours, by removing a very thin outline of foil round each; all the parts corresponding to one colour are afterwards connected.

As each shuttle is thrown, the battery is brought in contact with the appropriate series of insulated patches of tinfoil, producing a succession of different cards, and the pattern is not shifted for-

ward until all the colours are exhausted. After the completion of each fresh combination on the perforated plate, the battery-circuit is broken by a proper contact-breaker, and the injurious spark is thus avoided, which would otherwise occur when the comb is lifted from the pattern prior to a shift.

(307) **Concluding Remarks.**—It is impossible within the limits of this work to record all the applications of electricity to useful purposes. Thus it has been applied to register meteorological observations by Wheatstone, Du Moncel, Salleron, Hervé-Mangon, Hardy, Hough, Reynard, Guiot, Morin, Hipp, Liais, Secchi, Wild, and many others. It has been employed to record earthquake phenomena by Palmieri, and most physical phenomena are observed and recorded by its means. It is used in our homes as an article of household furniture to ring bells, to convey orders, and to indicate localities. It has been employed in the automatic performance of musical instruments, to record votes in assemblies like the French House of Commons, to indicate the progress and state of the game in billiard rooms, and for other innumerable purposes.

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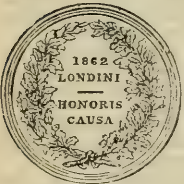

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